TWO STRATEGIES FOR ELECTRIC LOAD LEVELLING FOR INDIA
PHASE I

ADVISORY BOARD ON ENERGY
GOVERNMENT OF INDIA
MARCH 1988

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A STUDY
BY
TATA ENERGY RESEARCH INSTITUTE
NEW DELHI

ADVISORY BOARD ON ENERGY
GOVERNMENT OF INDIA
MARCH 1988

For Private Circulation Only

Other Publications of the Advisory Board on Energy

1. Recommendations (1984).
2. Towards a Perspective on Energy Demand and Supply in India in 2004/05 (May, 1985).
3. The Energy Scene (October 1985).
4. Energy Conservation (August 1986).
5. Feasibility of a Cogeneration Corporation (August 1986)
6. The Energy Scene (December 1986).
7. The Energy Scene (December 1987).
8. Issues in Coal (February 1988)

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TWO STRATEGIES FOR ELECTRIC LOAD LEVELLING FOR INDIA

PHASE I-FINAL REPORT

JANUARY, 1987

Submitted to : ADVISORY BOARD ON ENERGY
Submitted by : TATA ENERGY RESEARCH INSTITUTE, NEW DELHI

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PREFACE

This study has been undertaken with a view to explore the cost-effectiveness and impact of two strategies for reducing the peak load demand in the country. The first strategy deals with introduction of energy-efficient lighting technologies in the domestic and commercial sectors. The second strategy considers setting up two time-zones in the Eastern and Western parts of the country to stagger the clock related demand in these zones by one hour.

The study has been able to estimate the contribution of lighting load to the total electricity load in the country on an hour by hour basis. An exhaustive methodology for analysis of load curves has been developed, unfortunately unforeseen correlations between electric loads and climatic parameters have led to limited applicability of the techniques developed here to Bombay data. Possibly for the first time, a direct consumer survey with a scientifically selected sample has been used to carry out nation-wide estimates of hourly lighting loads of domestic and commercial consumers.

This study has been funded jointly by the Advisory Board on Energy and the Tata Energy Research Institute, and has been conducted by TERI staff. The results of this study, it is hoped, would contribute towards a rational investment policy and better demand management for the power sector in the country, as specifically related to lighting technologies and applications.

We would like to express our gratitude to Mr. R. Narasimhan (Chief Load Despatcher, Tata Electric Companies), Mr. Navkal, Mr. Divekar, Mr. Palwankar, Mr. Godse, Mr. Kamat, Mr. Gupte and Mr. Pathak all of BEST, Mr. S.M. Vidwans, Director, Bureau of Economics and Statistics, Government of Maharashtra, and Mr. R. Venkateshan, and Mr P.K. Bandyopadhyay of Philips. We would also like to thank the student surveyors from Bombay and Delhi who conscientiously and often painstakingly visited obscure addresses to conduct the survey in the respective cities. Finally, we are grateful to the consumers themselves who cooperated with us in the surveys in Bombay and Delhi.

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FOREWORD

One of the problems faced by the power utilities in the country is how to meet the daily peaking power demands, especially in the evenings, when substantial increases in lighting loads take place. The problem would have been less severe if the hydel-thermal generation mix (which, experts consider, should be in the ratio of 40:60, particularly to meet peaking demands) had not been allowed to deteriorate during the last two decades. The long term solution to this problem is the restoration of this balance by an accelerated development of hydel resources—a matter to which the Advisory Board on Energy has already drawn attention. However, since the creation of such an additional capacity to meet peaking demands is both costly and time-consuming, other means based on the conservation and more efficient use of energy, have to be necessarily thought of.

2. It was in this context that the Advisory Board on Energy commissioned the Tata Energy Research Institute, New Delhi to initiate studies on two strategies for reducing the lighting peak load demand in the country. The first deals with the introduction of energy-efficient lights and the second with the establishment of two time zones in the country with a view to displacing the clock related peak demand in the eastern and western part of the country by one hour.

3. The present publication contains the final Report in respect of the first strategy and is based on a sample survey in the Carnac sub-station area in Bombay. The Report comes to the conclusion that the replacement of incandescent lamps by fluorescent tubelights can contribute effectively to a reduction in the peak demand. This is so because a 20 W fluorescent tubelight gives the same light as a 100 Watt filament lamp but consumes far less energy. Although the cost of installation of a tubelight is around Rs. 120 and therefore far higher than that of a light point and bulb, the former nevertheless offers a cost-effective option because the additional outlay can be recovered in about 24 months as a result of recurring savings in the consumption of electricity. If such replacement is done on a mass scale, utilities would stand to gain by a substantial reduction in the evening peak demand. The Report estimates that, if there are no constraints in supply, the reduction in peak demand due to the all India replacement of incandescent lamps by 20W fluorescent tubes would be about 5,158 MW at the end-use point—translated in terms of installed generation capacity, the capacity released would be around 10,800 MW.

4. The Report also suggests the various measures—legal, fiscal and administrative—which may have to be taken to promote a large scale replacement of incandescent bulbs by energy-efficient fluorescent tubelights.

5. The Advisory Board on Energy has considered and welcomed this Report. It however feels that pilot studies will need to be taken up by various State Electricity Boards in order to identify the practical difficulties which will be encountered in any attempt to achieve a large-scale replacement of incandescent bulbs by tubelights. The Board also feels that the concerned interests will need to carry out an effective awareness campaign designed to convince the ordinary consumer that it is in his own interest to switch over from bulbs to tubelights.

6. It is hoped that this Report will help energy planners and energy administrators in all parts of the country to judge for themselves the undoubtedly great scope that exists to conserve our limited energy resources through the adoption of the strategy outlined in it.

(B.B. VOHRA)
Chairman

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INTRODUCTION

The demand for electricity is not fully met all over the country. The load restrictions range from 10% to 50% and almost all these restrictions come into effect during the whole or a part of the time period 5 pm to 10 pm. The occurrences of peak loads in the different systems in the country mostly fall between 5 pm to 9 pm with occasional exceptions.

The major problem in the power system has been its inability to meet the peak demand of the system. Several options are being considered to better meet the peak demand, and they fall into two categories:

(a) Add new capacity to meet the growing demand;
(b) Control/manage demand by substitution, conservation etc.

Addition of new capacity has always fallen short of targets over the different five-year plans. The targetted addition to installed capacity for the Sixth plan period was 19,600 MW whereas the actual additions totalled approximately 14,000 MW. Similar shortfalls are also expected in the Seventh five-year plan. The magnitude and impact of these shortfalls can be reduced by better demand management. This indicates need for additional emphasis on the second of the above mentioned options.

As mentioned earlier the peak load in almost all systems occurs between 5-9 pm. This is also the period when there is a sharp increase in the use of electric lighting in domestic and commercial units. It seemed evident that an attempt should be made to:

(a) Estimate the contribution of lighting to the peak load;
(b) Identify options to reduce this contribution.

The final project proposal incorporating the above goals and titled "Two Strategies for Electric Load Levelling for India" was submitted for approval to the Advisory Board on Energy (ABE) on February 21, 1984 following discussions held earlier with Mr. Sambamurthy of CEA, and Mr. Eswaran and Mr. Jairam Ramesh of ABE. ABE's support to the project was sanctioned in May, 1984 and the terms for undertaking the research were finalised in July, 1984.

The first and second progress reports were submitted to ABE on June, 1985 and January, 1986 respectively.

2. OBJECTIVES—PHASE I

The goals of the project proposal are related to two strategies for electric load levelling for India. The project is also divided into two phases with one phase focussing on each of the two strategies. The first phase studies the impact of introducing energy-efficient electric lighting. The second phase investigates the impact of establishing two time zones in the country with a view to displacing the clock related peak demand in the eastern and western parts of the country by one hour. The first phase concludes with the present progress report. **The objectives for Phase I of the project are:**

1. **Identify the contribution of domestic and commercial lighting to the peak load in a selected Indian city.**
2. **Use the above data to estimate the impact of using more efficient electric lighting technologies on all-India peak demand.**
3. **List out policy options to the Advisory Board on Energy, and identify directions for implementing the above objectives in a systematic manner.**

3. METHODOLOGY

Two different approaches (load analysis and direct consumer survey) were simultaneously adopted to arrive at the estimates of contribution of domestic and commercial lighting between 6 pm to 10 pm in South Bombay. The main reason for adopting these two independent approaches was to validate the load analysis methodology with results of the survey.

Even prior to receiving sanctioned funds from ABE, considerable spade work had been undertaken. TERI had written to Tata Electric Companies (TEC) seeking permission for obtaining electricity consumption data from Bombay. Collection of data from TEC and the Western Regional Electricity Board (WREB) was initiated in June '84, a month before the final sanction of the project proposal. TERI scientists visited Bombay in August '84 to discuss modalities of data collection for hourly load data from TEC and WREB.

The power supply in South Bombay almost exclusively catered to commercial and domestic consumers. There were no major industries in South Bombay. It was found that the hourly load data for South Bombay (as against load data for the whole of Bombay city) could be collected. The hourly generation allocated to the following four different electricity vendors serving Bombay and its suburbs was collected from TEC's Load Dispatch Centre.

- Tata Electric High Tension Consumers: These consumers purchase large amounts of power directly from TEC.
- Bombay Electric Supply and Transport Undertaking (BEST): BEST serves South and Central Bombay as well as several parts of North Bombay. The load curve for BEST show two daily peaks. The morning peak is generally higher than the evening peak.
- Maharashtra State Electricity Board (MSEB): MSEB serves mostly industrial enterprises operating in three shifts and hence has a fairly flat daily load curve. Some lighting load occurs even in the factories, and the load curve for MSEB shows a slight evening peak.
- Bombay Suburban Electric Supply (BSES): BSES mostly serves domestic consumers in North Bombay. Their load curve has a pronounced evening peak.

For the last five years or so TEC's Load Despatch Centre has had problems in meeting the growing demand for electricity for the Bombay region. To decrease the effective demand, a four pronged strategy was pursued. The options exercised in the order of decreasing frequency of occurrence were:

- Decreasing the system frequency: Decreasing the frequency of electric supply decreases the load from induction motors. This decrease has been estimated to be at the rate of 1.5% to 2% drop in the total load for each 1% drop in frequency.
- Scheduled cut-offs: This refers to power cuts with prior notice to consumers.
- Load shedding: This refers to unscheduled interruptions in power supply. There were about 1000 instances of load shedding in Bombay annually for the last five years.

- Purchase Restrictions: This essentially consists of restrictions imposed by MSEB on purchase of power by the Tata Electric Company which in turn passes on these purchase restrictions by distributing them among its high tension consumers, BEST and BSES. This is referred to as Load Restriction by power engineers.

The system data has been recorded more extensively in the recent years. For this reason it was decided to select data for analysis from the recent past although the electricity demand had not been entirely met in Bombay for the last five years; calendar year 1983 was chosen for study *Corrections were applied to the data to obtain the hourly demand unconstrained by the above four measures.* With the commissioning of TEC's 500 MW thermal power station in Bombay, the electricity demand of Bombay region is fully met. However, this change occurred only from April, 1984. Therefore, it was too early to obtain data on unconstrained hourly demand for Bombay for one full year, at the time of initiation of this study.

We obtained data for 8760 hours of the calendar year 1983 from TEC. Data was available as hand written numbers on large sheets of paper which was then transcribed and later entered into the computer for analysis. The following four types of data were obtained.

(a) Hourly data for the electricity generation from the Tata Railway System (the system is thus called because the railways have two small generating stations of about 60 MW each that are integrated with the Tata system).
(b) Hourly data on system frequency (this gives the average frequency for each hour)
(c) Hourly data on the scheduled cut-offs, if any.
(d) Hourly data of load shedding, if any.

By late August, 1984 it had become clear that the analysis should be focused on a particular level of aggregation in the electricity distribution system. The results from analysis of the sample survey are intended for a country-wide application. In such cases it is generally desirable to choose the sample to be spread over a large geographic area. On the other hand, the costs and organisational problems involved in selecting a representative sample and surveying it become unmanageable when the sample is spread over a wide area. The desirability of a large geographic spread of the sample arises if the parameter being surveyed is dependent on the location. Response to declining indoor natural illumination by domestic and commercial electricity consumers is not expected to be influenced by their geographic location Therefore, it was considered adequate to conduct a thorough and a reliable survey from a compact population of such consumers found in South Bombay. Data from this sub-section of the city would be amenable to numerical analysis for isolation of lighting component. It was expected that this numerical analysis methodology, after its validation by survey data, could then be used to analyse data from other load despatch centres and arrive at estimates of the national lighting load component as a fraction of the total load, during evening hours.

Customers of Bombay Electric Supply and Transport (BEST) Undertaking were identified as an attractive subject for this study. BEST has no high tension consumers, no major low tension industries, and no railway traction in their demand. BEST caters to domestic and commercial consumers in South and Central Bombay. The most suitable period for this study is when the days are neither too long nor too short as during spring and fall. However, the sky is often overcast in fall due to the tail-end of the monsoons. Thus spring (March-April) was selected as the suitable period for a direct consumer survey.

Computerisation of data from the load despatch centre of TEC has started only recently at their Bombay office. No printouts or computer tapes were available for the data that was needed; handwritten data of actual generation was obtained for analysis. The complete hourly data for the period preceding 1983 are hard to obtain, since only a portion of the data (only a few hours each day) were then being documented. From January to June 83, data for the period 11 pm to 6 am period had not been recorded, but this was not considered a serious handicap as described in section 4 below.

The TEC data entry was completed by January '85. The analysis of the load data obtained from TEC and WREB took longer than planned due to unexpected problems with the computer installation.

The strategy for analysis of load curves for the ABE project is described in Appendix A. A primer on the basics of lighting will be found in Appendix B. These two appendices together set the direction of work to be followed in terms of data analysis.

By February '85, TERI was in touch with several colleges of Bombay University whose students were interested in taking up survey work A map was obtained from BEST identifying the areas that were served by four different receiving stations in the North, South, East and West parts of Bombay. South and West Bombay areas, served by Carnac and Mahalakshmi receiving stations respectively, were identified as suitable sub-sections for validation of the numerical method by the consumer survey. Several BEST officers were contacted to clarify ambiguous data about the BEST receiving station at Mahalakshmi. Mahalakshmi area did not have data recorded prior to July, 1983 and hence could not be used for the present study South Bombay area, served by the Carnac receiving station was identified as the area to be surveyed. The plan of a Two Dimensional Systematic Sampling scheme is described in Appendices C & D.

Decline in outdoor natural illumination at dusk in Bombay was studied. Data on natural illumination levels near sunset time in Bombay is shown in Fig 3 1. Note that the vertical axis is logarithmic, and the illumination decreases by a factor of 10 from 5 30 pm to 6.20 pm. Sunset occurs at 6 30 p m., by which time the illumination drops by a factor of 40 from its value at 5.20 pm. **Almost all electric lighting gets switched on much before sunset time and not during one hour symetrically placed about sunset, as hypothesised in Appendix A.** This of course, in no way changes the procedure for analysis of the load curve described in Appendix A.

The probability of building occupants switching on electric lights as a function of a natural illumination level in the room is shown in Fig 3.2 for British consumers. This behaviour has been obtained from an extensive research project conducted by the Building Research Establishment of the Department of Environment (U.K.) on electric lighting use. The graph in Fig. 3.2 explains 70% of the variance in the data obtained from a number of different electric lighting installations with different populations, different occupancy patterns, different lighting design levels and for all times of the year.

Detailed experiments and surveys carried out during the summer of 1986 on a representative sample of electricity consumers in Delhi revealed that the probability of their switching on electric lights as a function of indoor natural illumination was very different from that shown in Fig. 3.2. This finding, given in Fig. 3.3, was very remarkable in light of the discovery that this response to natural illumination by Delhi residents was independent of household income levels, family size, and educational achievements of the members of the household. This finding is also significant in its implication regarding the impact of architectural factors on domestic electricity consumption.

4. LOAD ANALYSIS

The overall internal milestones for the two approaches are shown in Fig. 4.1. The activity details are:

1. Identify sample, prepare questionnaire, and undertake survey of the sample.
2. Identify sub-sample for daylight factor measurements in Bombay.
3. Obtain hourly temperature data for 1983 for Bombay.
4. Identify and eliminate the non-working days from the Bombay load data for 1983.
5. Obtain Piece-wise Linear and Continuous (PLC) load curve for Carnac.
6. Obtain hourly global radiation data for Bombay.
7. Enter survey data in the computer for analysis.
8. Enter hourly temperature data for analysis.
9. Undertake survey of daylight factors in Bombay.
10. Enter hourly global radiation data in the computer.
11. Obtain correlations between load and outdoor illumination levels based on sensitivity to illumination.
12. Complete analysis of survey data.
13. Obtain sensitivity of Bombay load to illumination levels and temperature by multiple regression analysis.
14. Compare results of survey with the results obtained from load analysis. Scale-up the Bombay findings to arrive at estimates for India.

The hourly data values for electricity demand for Bombay were double checked by comparing them with the annual mean and the standard deviation of the data for the respective hour of the day. Whenever the values were away from the mean by more than twice the standard deviation, they were double checked with the chief load despatcher of TEC in Bombay. All the data pertaining to the sample account numbers and alternate sample account numbers (as described in the first progress report) were obtained from BEST on a magnetic tape and transferred to TERI office in New Delhi. Global and diffuse solar radiation data for Bombay for the year 1983 was obtained from the Additional Director General of Meteorology (Research) from Pune. This data was the basis for analysing electricity use for lighting purposes.

The Piece-wise Linear the Continuous (PLC) load curve for the Carnac sub-station was obtained using the steps described below:

1. Since the Carnac load data for the hours 23-24 and 1-6 was missing from January to June 1983, the missing data was first reconstructed so as to get the histogram of hourly demand for the full calander year. For this reconstruction,the ratios for each of the hours (23, 24 and 1-6) between the Carnac load and the total Bombay load for the months July-December, 1983 (for which the data is available) were calculated on a monthly basis. It was found that the ratios

undergo a monotonic change from July-December reflecting a change in the relative composition of Carnac and Bombay loads (it is possible that these changes are not periodic with a one year period but reflect a secular change in the composition of Carnac and Bombay load; this possibility was presently ignored*).

2. The hourly load ratios were used to reconstruct the missing data in the following manner. The hourly load ratios for the month of December were taken to be equal to the hourly load ratios for the month of January. The months between January and June were sequentially matched with the months between December and July.

Based on the Bombay hourly radiation data for global and diffuse radiation, the complete global radiation data was reconstructed. This was necessary because there existed some gaps in the global and diffuse radiation data for Bombay due to intermittent equipment failures. Since not all gaps in global and diffuse radiation data were coincident, the ratios on an hourly basis for each month can be used to reconstruct the gaps in the global data. For those extremely rare instances, where both global and diffuse radiation data were missing, the global radiation data was reconstructed by filling in the gaps with data for the corresponding hours of the next day, or the previous day, or the day after the next, or the day before the previous one, taken in this order. This procedure enabled the reconstruction of hourly global radiation data for Bombay for the entire calendar year of 1983.

The procedure described below attempts to identify the component of the Carnac load which substitutes for daylighting. That part of the lighting load in Carnac which was independent of the daylight conditions (eg. lighting inside dark restaurants, theatres, in the interior of shops, godowns, etc) would not be identified by this analysis.

It was important to recognize that the response of electric demand to variation in daylighting was itself a function of the time of the day. People respond differently if the daylight decreases during office hours (eg. due to a heavily overcast monsoon sky or a total solar eclipse) compared to their response to decreased daylight availability in the morning hours or still differently in the evening hours. A general equation for describing the hourly load can be written as:

$$L(t) = A(t) + B(t) * F(I(t))$$

Where L(t) stands for the electric load at hour t(t= 1—24).
A(t) stands for that component of the load at hour t which is independent of daylight availability.
B(t) stands for the sensitivity of the load to the availability of daylight at hour t.
I(t) is the availability of indoor daylight at hour t.
F(x) is the response function for turning on electric lights as the illumination x changes, and F(x) has a general shape as shown in Fig 3.3.

A representative sub-sample of the Bombay sample was surveyed to determine the distribution of daylight factors+ in their premises. This distribution was taken as representative of the consumers in South Bombay. For a given level of outdoor natural illumination, the distribution of indoor illumination levels in South Bombay was obtained using this data. This distribution of indoor illumination levels was used to determine the probability distribution of switching on electric lights using data from the survey carried out in Delhi. The weighted sum of these probabilities was taken as the cumulative probability of lights being switched on. An attempt was made to correlate this hourly probability and outdoor temperature with load for 8760 hours in the year.

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* This should have been done after the Bombay hourly load data and the Carnac data were normalized to remove any secular increase from January to December 1983 This procedure would have ensured that the monotonic changes seen in the hourly load ratios for each month from July to December were not a reflection of a secular trend but reflect truly annually periodic behaviour Since the above correction had to be done sooner or later, it was probably better to do it, to avoid interference from secular trends

+ Daylight factor equals the ratio of indoor natural illumination on a horizontal surface at table-top height to the outdoor natural illumination on a horizontal surface at the same time.

For 24 hours of the day and 365 days of the year, one can obtain 8760 equations after substituting numbers for L(t) and F(I(t) for each hour of the year. There are only 48 unknowns in the equations. Thus one could find the least square fit to obtain best estimates for the 48 unknowns

The above approach has two problems. First F(x) tends to saturate at high and low levels of daylight illumination (it takes values of one and zero when the illumination is very low or very high). Thus one would be able to estimate B(t) only for those values of t for which F(I(t)) is not saturated. Heavily overcast Bombay sky during the monsoon produces very low levels of daytime illumination even during office hours, and thus could contribute towards identifying values of B(t) even for daytime hours. A simpler approach would be to assume that B(t) is a constant, equal to B. Then one simply has 8760 equations in 25 unknowns—24 values of A(t) and B.

The second problem was the sensitivity of the calculated estimates of B(t) to the shape of function F(x), and the scaling factor assumed for converting global radiation into indoor daylight illumination. It is possible to do this conversion more carefully by tracking the position of the sun in the sky and using the solar altitude to determine the ratio of outdoor illumination to the outdoor global radiation. Low solar altitudes cause sunlight to pass through larger atmospheric mass and this preferentially depletes the blue-green component of the sunlight. This causes outdoor illumination to decrease faster than the energy content of the global radiation as the sun approaches the horizon. This refinement has been ignored since the low daylight factors in Bombay (of the order of 0 001) cause indoor natural illumination to decline much before significant spectral changes in sunlight begin to occur in the evening

Another refinement to the above approach would be to include the effect of hysterysis to F(x) (the curve of F(x) with increasing x is somewhat different from the curve with decreasing x). In this first analysis, it is assumed that this effect can be safely ignored.

The daylight factors for the representative subsample of South Bombay electricity consumers were put together with the Piece-wise Linear Continuous Carnac load curve obtained after removal of secular trends as indicated in the preceding pages. The global radiation data for Bombay for 1983 was correlated with the Carnac load curve using the response function as described earlier.

In spite of extensive efforts carried out to extract data, the sophisticated methods applied to the analysis of Bombay load did not produce a satisfactory and clear-cut answer in terms of the contribution of lighting to total demand. The reason for this lies basically in the strong correlation between high ambient temperature and large availability of natural illumination. Higher ambient temperatures increase electricity consumption in cooling equipment (fans, air-conditioners, etc). The increased availability of natural illumination (and the resulting reduction in electric lighting) gets easily masked by the increased energy demand for cooling.

It is perhaps possible that the load analysis methodology would be effective in a location where cooling and natural illumination were not so closely linked. For example, in a temperate city like Bangalore, evenings are only moderately warm in summer and only moderately cool in winter. The analysis methodology developed for this study may yield answers in such a location since a few degrees variation in the ambient temperatures does not heavily influence energy demand for space conditioning. It is believed that this may be the cause for the lack of success in applying this methodology to the Bombay load curve.

5. SURVEY—TECHNIQUE AND RESULTS

The technique of sample selection and the survey procedure has already been described in detail in Appendices C and D. Survey questionnaires for domestic and commercial consumers are reproduced in Appendix E.

Data pertaining to the half hourly distribution of electric lighting for a 24 hour period was obtained from the survey Data on the disaggregation of use of incandescent lamps by wattage (40, 60 Watts and 100 Watts) and flourescent lamps was also collected The load curve for domestic consumers is shown in Fig. 5.1 From this figure it is clear that domestic consumption of electricity for lighting has two peaks. The smaller of the two peaks is between 5 30 am to 8 am and the second larger peak occurs between 6 pm to 11 pm (the widths of the peaks have been measured as Full Width at Half Maximum, FWHM). The load curve for commercial consumers is shown in Fig 5.2 **The commercial lighting load shows no significant morning peak. The lighting load increases from 10 am and has a plateau till 5 pm after which it increases sharply to its maximum value at 6 pm followed by a rapid decline from 8 pm onwards.** The shoulder in the afternoon arises mostly from the office use of electric lighting, while **the evening peak contribution is mostly from shops.** The electric lighting used in shops more than compensates for the decline in electricity use in office lighting in the evening. If fact, **the total commercial lighting load in the evening increases by a factor of 1.6 over its value in the afternoon.** The lighting load curve for the entire Carnac sample is shown in Fig. 5.3 disaggregated by end use (domestic/commercial), and in Fig 5 4 disaggregated by lighting technology and wattage In Fig. 5.4 **the occurrence of incandescent lighting load coincides with the system peak between 6-10 p.m. This is significant since incandescent lamps have the lowest luminous efficacy of all electric lighting technologies.**

The above data can also be analysed in terms of the fraction (percentage) of installed wattage of lamps that is being used at any given time of the day. This data would enable an estimation of the time-profile (duty cycle) of actual use of a "typical" lamp installed in domestic/commercial environment The data for incandescent and fluorescent lamps is given in Figs 5 5 and 5.6 respectively and the numerical values are reported in Table 5.1. **The low duty cycle of incandescent lamps during the day time is a reflection of their more intensive use in residences.** This probably occurs because those commercial establishments using artificial lighting during office hours have extended use of electric lamps They, therefore, need to pay attention to the luminous efficacy of the lamps they use. Also, both offices and shops have adequate resources (as compared to households) to make the necessary initial investments in improving the energy efficiency of their lighting systems so as to obtain lower life cycle costs for the electric lamps they use **Domestic users, on the other hand, are often reluctant to use fluorescent lamps because: (i) the duty cycle of lighting in the domestic units is short; (ii) they often do not have enough resources for making the initial capital investments in fluorescent lighting to obtain lower life cycle costs; and (iii) in the absence of a peak load pricing system, there are no incentives for using lamps of high luminous efficacy at peak time.**

Since the Carnac sample has been chosen carefully as described earlier, it is quite straight forward to estimate the total Carnac lighting load by scaling up the data from the survey. The lighting contribution to the total Carnac load obtained from this procedure is shown in the Fig. 5.7. The lighting load as a fraction of the total load in South Bombay reaches a maximum (37%) at 7 pm. Though this is not peak load time for the Carnac subsystem (owing to the predominance of commercial buildings there), this is the peak load time for WREB of which Carnac is an integral part. The data on lighting loads are tabulated in Table 5.2.

TABLE 5.1

Duty Cycle of Incandescent and Fluorescent Lamps in South Bombay (March-April)

Time (Hr. after midnight)	Duty Cycles (%) Incandescent	Fluorescent
4.00	0.30	0.25
4.30	0.56	0.25
5.00	3.63	3.96
5.30	4.31	5.23
6.00	6.74	8.06
6.30	6.11	7.01
7.00	5.77	7.17
7.30	4.10	5.39
8.00	3.85	5.46
8.30	3.23	7.58
9.00	4.59	15.26
9.30	4.75	20.93
10.00	5.65	30.73
10.30	5.80	35.17
11.00	6.27	39.01
11.30	8.45	41.74
12.00	9.23	42.75
12.30	9.20	42.40
13.00	9.05	42.28
13.30	8.70	41.39
14.00	8.90	41.58
14.30	8.87	41.29
15.00	8.93	41.26
15.30	8.44	41.45
16.00	8.56	42.47
16.30	8.32	41.61
17.00	10.36	44.47
17.30	11.84	43.51
18.00	22.81	69.47

TABLE 5.1
(Continued)

Time (Hr. after midnight)	Duty Cycles(%) Incandescent	 Fluorescent
18.30	33.49	54 69
19.00	38.02	52.24
19.30	36.84	45.99
20.00	36.13	42.56
20 30	26.97	32.02
21.00	26.36	29.89
21.30	23 75	27.16
22 00	24.02	26.04
22.30	19.83	18.38
23.00	12.23	13.04
23.30	5.58	5.01
24.00	2.76	2.98

TABLE 5.2

Lighting Load and Total Load Details for South Bombay

Time after Midnight (Hrs.)	Total Carnac Load (MW)	Lighting Load (MW)	Lighting Load as Percent of Total Carnac Load (%)
4	48.74	0.30	0.617
5	49.59	4.09	8.251
6	59.46	7 94	13 350
7	79.2	6 93	8 753
8	95.97	4 96	5.170
9	115.04	10.28	8.936
10	131 97	18 62	14.110
11	155.46	23.12	14.870
12	160 46	26.70	16 641
13	152 54	26 36	17.282
14	144 48	25 93	17.944
15	149 76	25 78	17.217
16	150.84	26.17	17.350
17	146 62	28 21	19 242
18	134 32	47 93	35.687
19	129 7	48.18	37.147
20	132 37	42 25	31 920
21	112.72	30 25	26 834
22	102.48	26.96	26.310
23	85.17	13 62	15 991
24	66 91	3 09	4 625

6. ALL-INDIA ESTIMATES

The data collected from the Bombay survey was scaled up to arrive at all-India estimates.

The Carnac sample is urban and more affluent than the average Indian electricty consumer. As a result it is likely that the Carnac consumer would tend to have more lamps installed in his/her premises than the average Indian domestic/commercial consumer.

On the other hand, **TERI conducted detailed surveys which showed that sensitivity to lighting (the level of natural illumination below which the person will switch on electric lighting) is independent of educational attainment, level of household income, and other social parameters.** Thus the Carnac consumer would not tend to switch on electric lighting at a higher level of natural indoor illumination than the average national consumer. Changes between the Carnac consumer and the average national consumer would be reflected in:

— The average national consumer has fewer lighting points and thus likely to use these lighting points more intensively than Carnac consumer, and

— The national consumer probably installs lamps of lower wattage and more incandescent lamps than fluorescent lamps as compared to the Carnac consumer, owing to a lower level of household income

Adjustments in the analysis can be made for the second point by using real data on number and wattage of lamps produced in the country. From these, the number and wattage of lamps currently installed in the country can be estimated. The first point is difficult to correct for in a quantitative manner. However, the safe assumption to make is that the intensities of use (duty cycles) of installed wattage of electric lamps in the rest of India are the same as those observed in South Bombay. Any error due to this assumption would give estimates of all India lighting load lower than the actual. This would tend to underestimate the potential for savings in peak demand by energy-efficient lighting technology. Thus we would err on the safe side by accepting this assumption for estimating maximum potential savings—the actual value my be higher than the estimate.

The life of an incandescent light bulb is approximately 1000 burning hours at 230 volts according to ISI specifications. In practice, most parts of the country have supply voltages less than 230 volts during evening hours. This increases the life of an incandescent lamp enormously.

For the analysis given in the following pages, another assumption made is that the number o incandescent lamps installed in the country equals the annual production of incandescent lamps and the number of fluorescent lamps installed in the country equals the total of the previous five years' production. These numbers are again conservative, and the lamp populations are estimated at 290 million and 162 69 million respectively. The life of an incandescent lamp is more sensitive to voltage than that of a fluorescent lamp. If the actual lamp populations are different than ou estimates because of undervoltage, there would be a more than proportionate increase in the incandescent lamp population than in the fluorescent lamp population. Again any error in the assumption made here is likely to underestimate the potential for decreasing the peak demand—

the actual potential will be larger than our estimate. A sensitivity analysis to indicate the effects of variation in these assumptions has also been carried out and is presented below.

The duty cycles of incandescent and fluorescent lamps in the Carnac sample, shown in Figs. 5.5 and 5.6, have been used with the estimates of installed wattage of lamps in the country to arrive at the estimated lighting load for the country as a whole as a function of time. In these calculations, the assumption made is that all fluorescent lamps are rated at 50W (inclusive of losses in the choke) and the weighted average wattage of incandescent lamps in service in the country is 65.5W. (These numbers are based on discussions with lamp manufacturers). The lighting load in the country calculated under these assumptions is referred to as the "base" case. The lighting load as a function of time is shown in Fig. 6.1. Also shown in this figure are sensitivity curves showing the estimates of the lighting load for the following two cases:

CASE I: The number of incandescent lamps installed in the country is taken as 319 million units (110% of the base estimate) and the duty cycle of these lamps at any time is estimated at 105% of the base estimate. At the same time the number of fluorescent lamps installed is taken as 146.42 million (90% of the base estimate) and the duty cycle of the fluorescent lamps as 95% of the base estimate of the duty cycle (refer Table 5.1 for baseline data).

CASE II: The number of incandescent lamps installed in the country is taken as 261 million (90% of the base estimate) and the duty cycle as 95% of the base estimate. The fluorescent lamps installed in the country is estimated at 178.96 million (110% of the base estimate) and the duty cycle as 105% of the base estimate.

These two cases represent two extremes. In the first case incandescent lamps are more in number and more intensively used, simultaneously with fewer number of fluorescent lamps with less intensive use in the country. This case would give higher potential savings than the base case. In the second case the assumption is that fewer incandescent lamps are installed in the country with less intensive duty cycle concurrently with larger number of fluorescent lamps with more intensive duty cycle. This case would give a lower estimation of the potential savings resulting from replacing all incandescent lamps with fluorescents. Sensitivity calculations using these two cases are presented in Table 6.1 at the end of this section.

According to estimates, the lighting load peaks between 5.30 pm to 10 pm with the maximum value of approximately 11,472 MW at 7pm. This is comprised of 7223 MW load from incandescent lamps and 4249 MW from fluorescent lamps. In terms of the existing lighting technologies available in India, the only high efficacy replacement for incandescent lamps (in the range of 25W to 150W) are the standard 20W or 40W fluorescent lamps. **A 20W fluorescent lamp (with 5W consumption in the choke) gives the same amount of light as a 100W incandescent lamp.** If all the incandescent lamps (average wattage 65.5W) used in domestic/commercial locations in the country were to be replaced with 20W fluorescent lamps, the resulting lighting load as a function of time is shown in Fig. 6.3 together with the base estimate. **Of course it is not cost-effective to replace those incandescent lamps which have low duty cycles (lamps in bathrooms, toilets, in residential staircases, etc) with fluorescent lamps.** However, for the sake of a conservative analysis

A 20W flourescent lamp has a luminous efficacy of 55 lumens/watt and will produce 1100 lumens This light output is only slightly less than the illumination obtained from a 100W incandescent lamp Since most of the incandescent lamps in the country are rated at 40-60W, this proposal will approximately double the illumination available to the user, in addition to savings to the economy this distinction has not been made. **The base proposal in terms of existing indigenous technology is to replace all incandescent lamps with 20W fluroescent lamps*. The savings in peak load resulting from this replacement (termed as maximum potential savings with technology available in India) will equal 4167 MW at the end-use point, which would equal 5000 MW at the generation point. This is equivalent to 8726 MW in terms of installed capacity* assuming a thermal plant availability factor, at peak load time, of 0.573.**

Assuming a rate of investment in generation and T&D of Rs. 1.2 crores/MW of installed capacity, the savings to the economy in terms of reduced investments in the power sector to meet the peak demand will be Rs. 10,471 crores. The cost of substituting the incandescent lamps by fluorescent lamps is estimated at Rs. 2320 crores. This is based on a retail price of Rs. 80/unit for the best quality 20W fluorescent lamp, including the cost of choke and fixture.

Seen alternatively, for every crore of rupees invested in replacing existing incandescent lamps with 20W fluorescent lamps with fixtures, 3.76 MW of installed capacity is released at peak load time to the system.

In addition to doubling available illumination, and saving Rs. 8151 crores (Rs. 10,471 crores saved in power generation and T&D by investing Rs. 2320 crores in fluorescent lamps and fixtures), this proposal will also save 10.58 x 10^9 units of electrical energy consumption per year worth Rs. 1206 crores at the marginal cost of Rs. 1.14/unit consumed. This represents an annual return on investments (made in lamp replacement) of 52%.

Fluorescent lamps can be substituted in place of incandescent lamps without changing the present levels of illumination by installing low power fluorescent lamps. Such compact fluorescent lamps are already commercially available and in use in the United States, Western Europe, Japan, and several South-East Asian countries. This lighting technology can be considered as proven. These fluorescent lamps are rated at about 8W and consume about 10W of power after taking into account power losses in the choke The lamps retail at the present for about US$ 10 (Rs. 130/-) per piece. If these lamps are produced in India and are used in place of incandescent lamps, the maximum potential savings can be estimated in the same manner as described above. The contribution to electric load from lighting resulting from such a replacement on an all-India basis is shown in Fig. 6.3. The savings in evening peak load is estimated at 5159 MW at the end-use point; this translates to 6191 MW at generation point, and equals 10,804 MW in terms of installed capacity. The cost of replacing 290 million incandescent lamps with these low power fluorescent lamps would be Rs. 3770 crores, Thus for every crore of rupees invested in replacing incandescent lamps with state-of-the-art compact fluorescent lamps, 2 87 MW of installed capacity will be released to the system at peak load time. If fully implemented, this option will save the economy Rs. 12,965 crores of investment in generation and T&D, for an investment of Rs. 3770 crores in low power (10W) fluorescent lamps. The annual savings in electrical energy consumption will be 14.49 x 10^9 units worth Rs. 1652 crores annually (at rates mentioned earlier). This equals an annual rate of return on investments (made in lamp replacement) of 43.8%. The all-India electric lighting load for these two options is compared with the existing lighting load in Figs. 6.2 and 6 3.

This is based on an average plant availability factor, of 57 3% (obained from discussions with Director (Planning), CEA) We understand from CEA that exact paint availability at peak load time is not known even to CEA, but is estimated at less than 60% by them CEA uses 57 3% as the plant availability factor at all times in their power projection calculations

The above estimates are conservative, since at every point of uncertainty in the preceding analysis, an attempt has been made to select the conservative assumption from amongst the available options. A sensitivity analysis of the results is presented in Table 6.1 with respect to the two cases (I an II) defined earlier in this section.

TABLE 6.1

Sensitivity Analysis of Results

	Case I*	Base Case	Case II*
Peak lighting load (MW) (at point of end-use)	11,975 MW	11,472 MW	11,083 MW
Technical option I (Replacement with 20W Fluorescents)			
1.1 Reduction in demand at end-use point	5,158 MW	4,167 MW	3,142 MW
1.2 Installed capacity released at peak load	10,802 MW	8,726 MW	6,580 MW
1.3 Investment saved in generation & T&D (1986 Rs.)	12,962 crores	10,471 crores	7,896 crores
1.4 Expenditure on installation of 20W lamps and fixtures (1986 Rs.)	2,552 crores	2,320 crores	2,088 crores
1.5 Net savings (1.3-1.4) (1986 Rs.)	10,410 crores	8,151 crores	5,808 crores
1.6 Installed capacity released/crore of Rs spent on lamp replacement	4.23 MW/crore	3.76 MW/crore	3.15 MW/crore
1.7 Decrease in annual electricity use (Kwh)	12.22×10^9	10.58×10^9	9.04×10^9
1.8 Marginal Value of electricity saved annually (1986 Rs.)	1,393 crores	1,206 crores	1,030 crores
1.9 Annual return on expenditure for lamp substitution in electricity saved	54.6%	52.0%	49.4%

* See Page 15 for definitions of these cases

TABLE 6.1
(Continued)

	Case I	Base Case	Case II
Technical Option II (Replacement with 10W compact fluorescents)			
2.1 Reduction in demand at end-use point	6,379 MW	5,159 MW	3,990 MW
2.2 Installed capacity released at peak load	13,360 MW	10,804 MW	8,357 MW
2.3 Investment saved in generation and T&D (1986 Rs.)	16,032 crores	12,965 crores	10,028 crores
2.4 Expenditure on installation of 10W lamps (1986 Rs.)	4,147 crores	3,770 crores	3,393 crores
2.5 Net savings (2 3-2 4), (1986 Rs.)	11,885 crores	9,195 crores	6,635 crores
2.6 Installed capacity released per crore of rupees spent on lamp replacement	3.22 MW/crore	2.87 MW/crore	2 46 MW/crore
2.7 Decrease in annual electricity use (Kwh)	16.74×10^9	$14\ 49 \times 10^9$	$12\ 39 \times 10^9$
2.8 Marginal value of electricity saved annually (1986 Rs.)	1,908 crores	1,652 crores	1,412 crores
2.9 Annual return on expenditure for lamp substitution in electricity saved	46 0%	43 8%	41 6%

7. POLICY OPTIONS

The various alternatives for achieving the potential load savings at peak time resulting from the use of energy efficient lighting can be broadly categorised in five areas:

(A) Legislation
(B) Financial (Credit) Policy
(C) Tax Structure
(D) Education
(E) Organisational Support

These are spelled out in more detail below.

A. Legislation

1. To improve the energy efficiency of lighting in the new stock of buildings (i.e. buildings which will be designed and constructed in the future), **it may be desirable to legislate installation of at least one fluorescent light in every room of the new building as a requirement for obtaining the building completion certificate.** It is expected that with the installation of the fluorescent lamps, the tendency to use these by the occupants would increase. Indonesia, for example, has a similar but weaker legislation that requires installation of one fluorescent lamp in every apartment/residential unit for obtaining compliance with the building regulations.

2. The Indian Government at the central, state and municipal levels is the single largest employer in the country. A large number of government employees either live in government quarters or qualify for government housing loans. Government quarters as well as houses built by government employees using government funds can be required to install fluorescent lighting.

3. Financial institutions such as LIC, HDFC, etc. provide loans to various individuals for constructing residential units. Since the financial institutions are under government control, it is possible that **installation of fluorescent lighting can be a requirement for compliance with the loan formalities.**

4. For improving the efficacy of lighting in the existing stock of buildings, a different approach would have to be followed All existing residential and commercial units pay a building tax to their respective municipalities. **A rebate on the tax payable to the municipality may be announced for those units which have fluorescent lighting installed in each room.** (To ease the problems arising from shortage of fluorescent lamps if such a policy were to be effected suddenly, the announcement of the policy can be made several months before its date of implementation). The Central government may compensate the municipality for any resulting loss of revenue.

5. **Licensing procedure for production of lamps of high luminous efficacy (say above 40 lumens/watt) can be liberalised or deregulated altogether.** Production of chokes, fixtures, etc. of high energy efficiency can also be liberalised or deregulated. At present, licensing for any additional capacity for production of chokes has been restricted to the small sector.

B. Financial (credit) Policy

1. **For large consumers it may be possible to establish a circulating fund for upgrading the incandescent lamp points to "fluorescent lamp points" (this includes choke, starter and the patti). Since the switch over from incandescent to fluorescent lamp points can take place in a phased manner, such circulating funds can be quite small and can be locally managed for better effectiveness.**

2. **Local utilities and state electricity boards can provide fluorescent lamp points to end-users on a hire and purchase basis.** This system has an additonal advantage in implementation since the lease payments can be automatically added to the electricity bill of the customer. **Experience in the developed countries has shown that electricity conservation programmes managed by the utilities have been very successful whenever a small staff has been set up within the utility with exclusive responsibility for electricity conservation measures. In those cases where the responsibility was added on to existing responsibilites of some utility staff, the conservation programmes have generally tended to fail.**

C. Tax Structure

1. The Central Government directly regulates the rate of excise duty charged on various commercial items. **It is recommended that the excise duty structure on lamps for general indoor lighting in domestic/commercial buildings should be designed in slabs of luminous efficacy of the lighting devices.** Presently this practice is not followed and the excise duty structure does not favour high luminous efficacy lamps. At the state level (and at the central level in Union Territories) a similar tax structure can be followed.

2. Presently, import of capital equipment for production of low wattage lamps of high luminous efficacy attracts heavy customs duty. This can be reduced considerably since the benefits to the Indian economy from large scale use of high efficacy lamps will greatly outweigh any loss of revenue resulting from reduced customs duty on capital equipment for their production

D. Education

1. It is important to **organise consumer education campaigns to remove misconceptions, prejudices and reluctance to use fluorescent lamps in place of incandescent lamps, particularly at the domestic level.**

2. **Training programmes for policy makers** at the municipal, state and central government levels have to be organised for effectively implementing the measures outlined earlier in this section.

3. Enthusiastic support from utilities and state electricity boards will be required if they are to operate hire purchase schemes for fluorescent lamp points for their customers. Training programmes for organizing hire-purchase schemes need to be held for officers from utilities and SEB's.

4. **Producers of lamps should be encouraged to keep their technology up-to-date.** They should also be encouraged to offer a variety of high-efficacy low-wattage lamps to domestic and

commercial consumers to enable increased acceptance of these lamps in the market. In this context, it is important to note that no Indian manufacturer markets fluorescent lamps of "warm white" colour, which seem to be more acceptable to domestic consumers in developed countries than "cool daylight" colour presently produced in this country.

E. Organisational Support

1. **The Indian Standards Institution should establish facilities for testing luminous efficacies of a variety of lamps.** The existing facilities should be considerably strengthened and expanded so that ISI certification can be obtained rapidly. ISI should also award luminous efficacy grades to lamps in order that the excise and tax structure can be linked to these grades. Energy efficiency of chokes should become a subject of ISI regulation since poor quality chokes can waste as much as 25% of the energy consumed in fluorescent lighting systems.

2. Organisational systems for operating hire purchase arrangements of fluorescent lamp points should be established in local utilities and state electricity boards. These schemes should first be implemented in those areas where the supply voltage is adequately high for using fluorescent lamps.

3. **In those areas where the supply voltage is not adequate, investments have to be made in upgrading transmission and distribution facilities to bring the supply voltage to the level required for operating fluorescent lamps.**

4. In those localities where the SEBs and local utilities encourage a large scale switch over to fluorescent lamps, capacitors for power factor correction should be integrated with local T&D network.

5. **An office for demand management (with no other additional responsibilities) should be created in every utility.** This office should have the responsibility of implementing energy-efficient technologies, and studying and recommending various policy and tariff options for the utility customers to reduce the peak load demand

Implementation of above options

Before initiating country-wide action for reducing the peak demand arising from domestic and commercial lighting, it is recommended that **a pilot scale demonstration should be launched at one or two locations. These locations should be selected with the following criteria in mind.**

- It should be possible to monitor the load at the site on an hourly basis Data on hourly loads for this location should be available for the last 2-3 years.

- The site should be served by a utility known for its dynamism and efficiency.

- The demand for electricity at the location should be almost exclusively from domestic and small commercial consumers.

- The site should have a reliable power supply with stable voltage levels. This is necessary for operating the fluorescent lamps efficiently.

- **It is advantageous to have a computerised billing system at the site. This will facilitate monitoring of consumer response by conducting direct consumer surveys, if necessary.**

- **The utility serving the area must have a positive attitude towards setting up an energy conservation cell, whose officers will have the primary responsibility for executing the pilot project.**

Two suitable sites which satisfy the above requirements are South Bombay and Ahmedabad.

It is recommended that **all the policy options described in this section should be brought to bear on the chosen site (s).** Results can be monitored for a period of twelve months and changes in the hourly load noted for comparison with recent records The results from this pilot study would provide valuable data and lessons for further large-scale implementation

FIGURE 3.1
CHANGE IN OUTDOOR ILLUMINANCE LEVEL OF DAYLIGHT DURING DUSK
BOMBAY, JANUARY 28, 1985

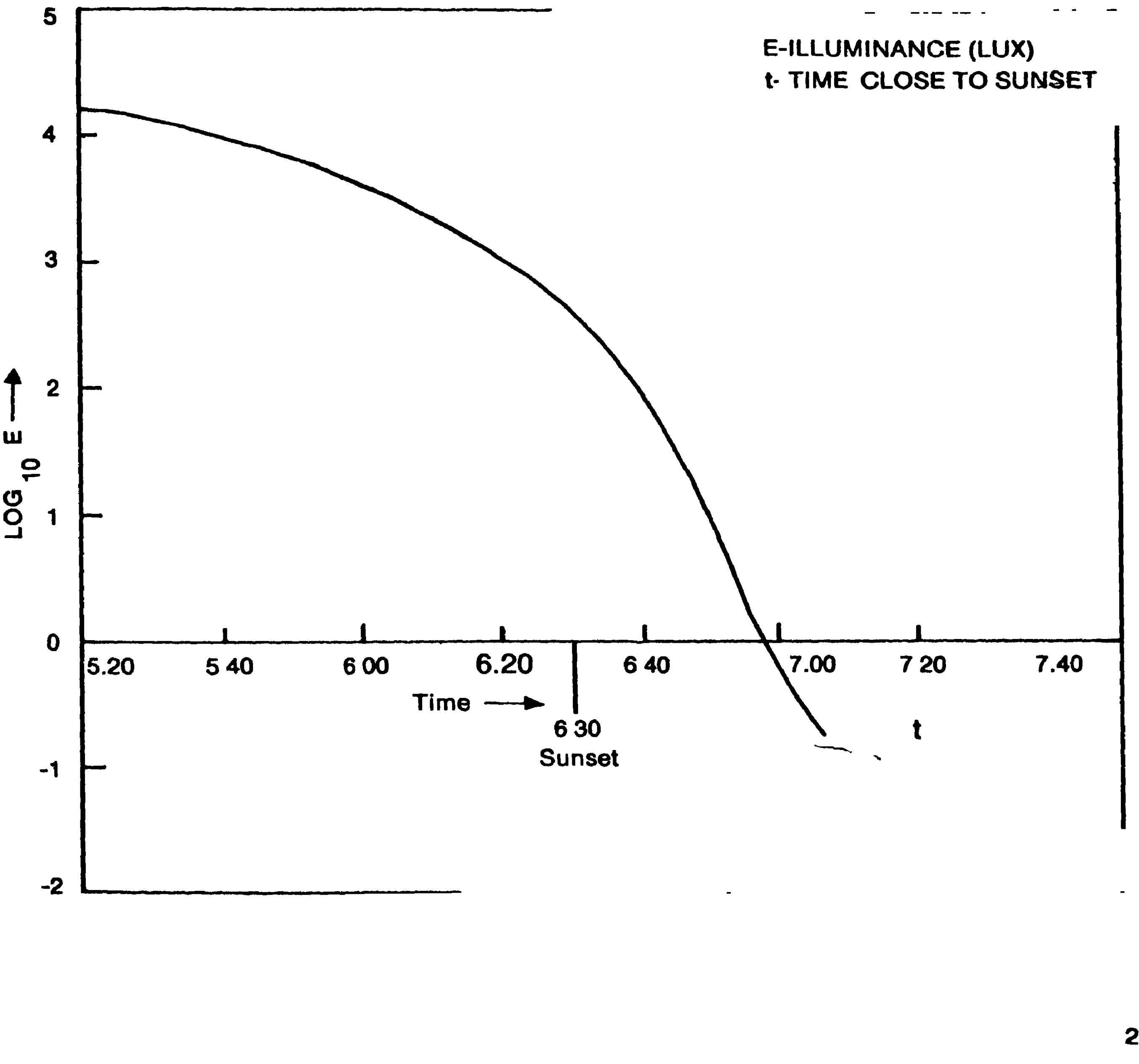


FIGURE 3.2

PERCENT OF PEOPLE SWITCHING ON LIGHTS AS A FUNCTION OF INDOOR ILLUMINATION LEVEL

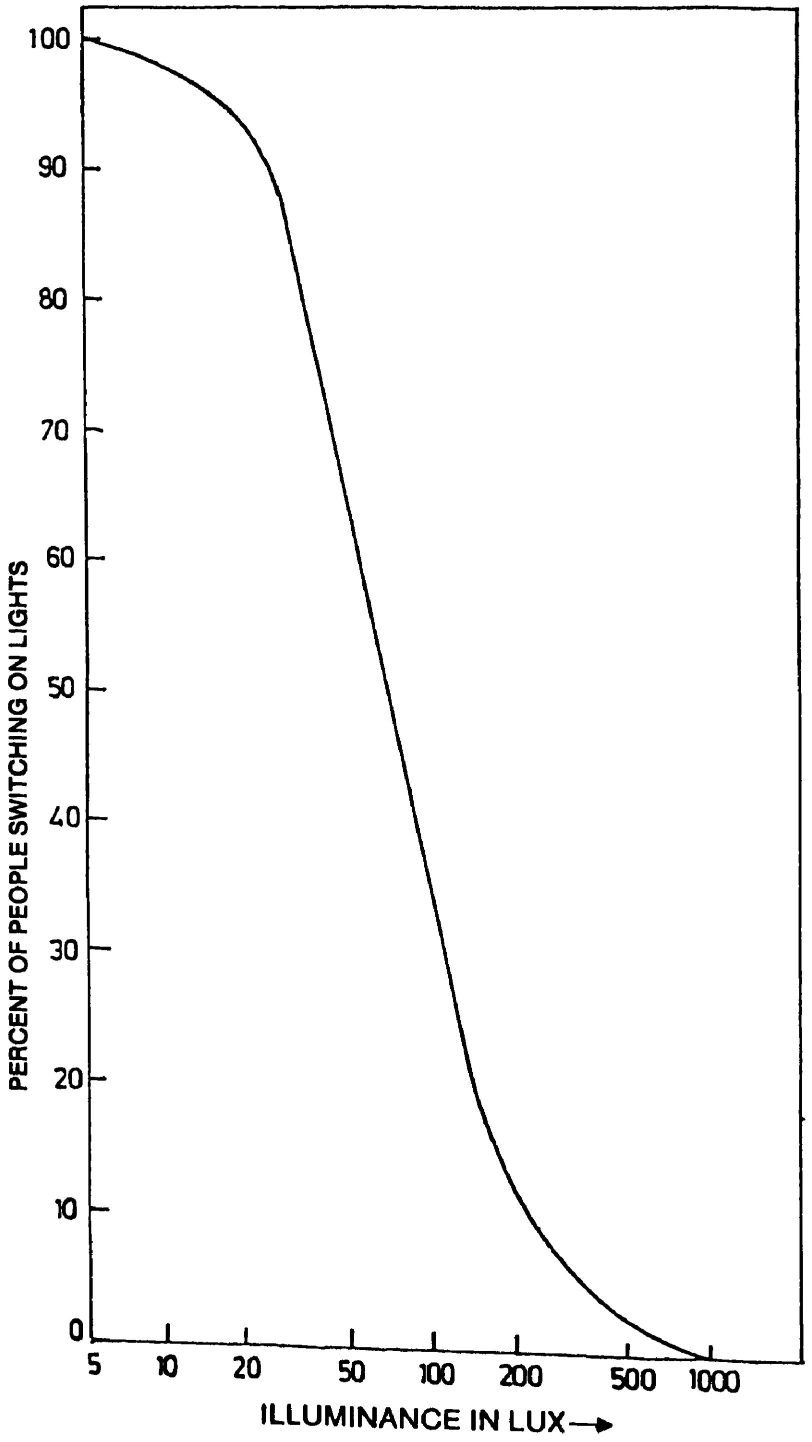
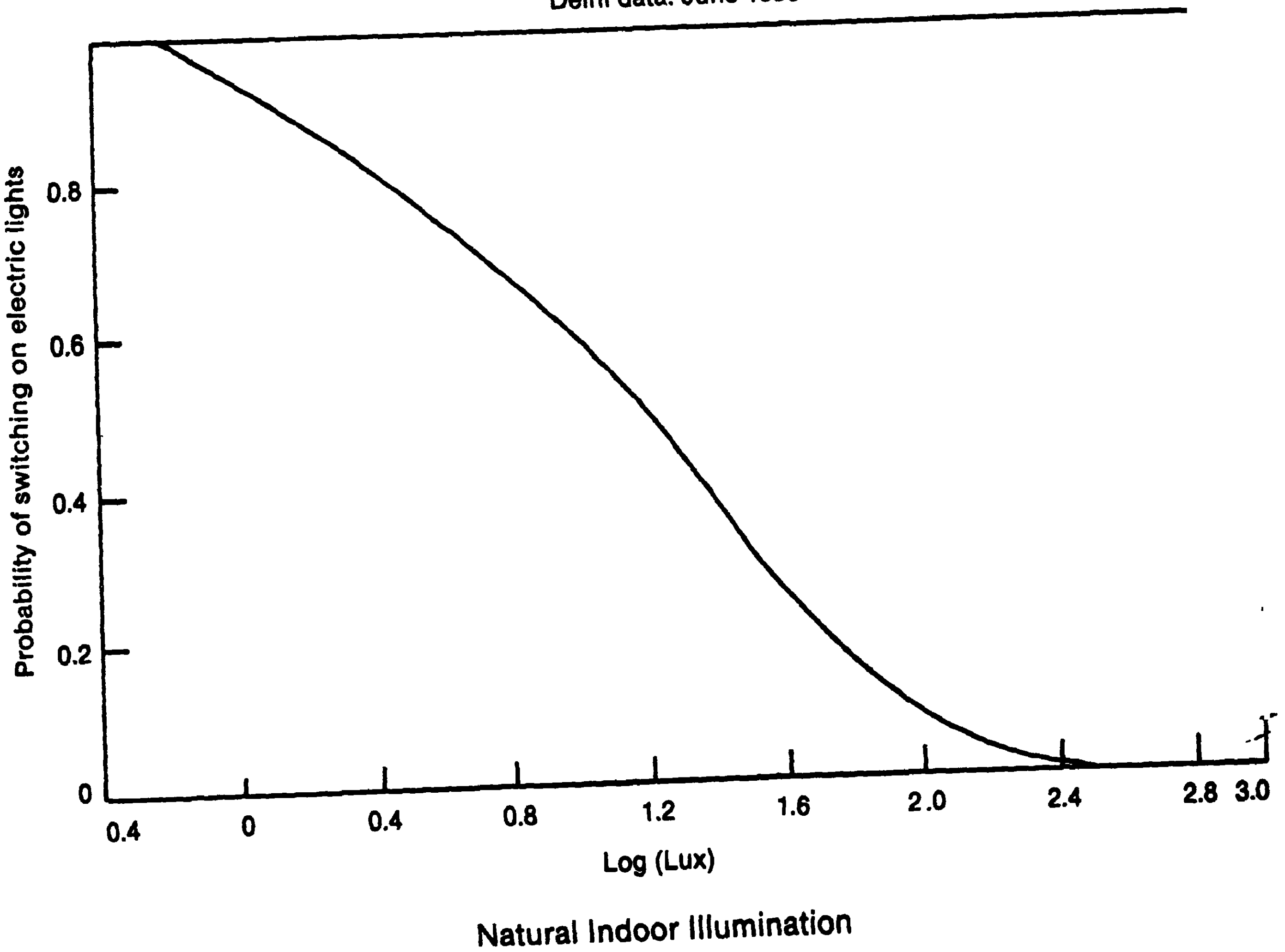


FIGURE 3.3

PROBABILITY CURVE FOR USE OF ELECTRIC LIGHTING

Delhı data. June 1986



ABE PHASE I

The pathways for various internal milestones for this phase are shown below.

FIGURE 4.1

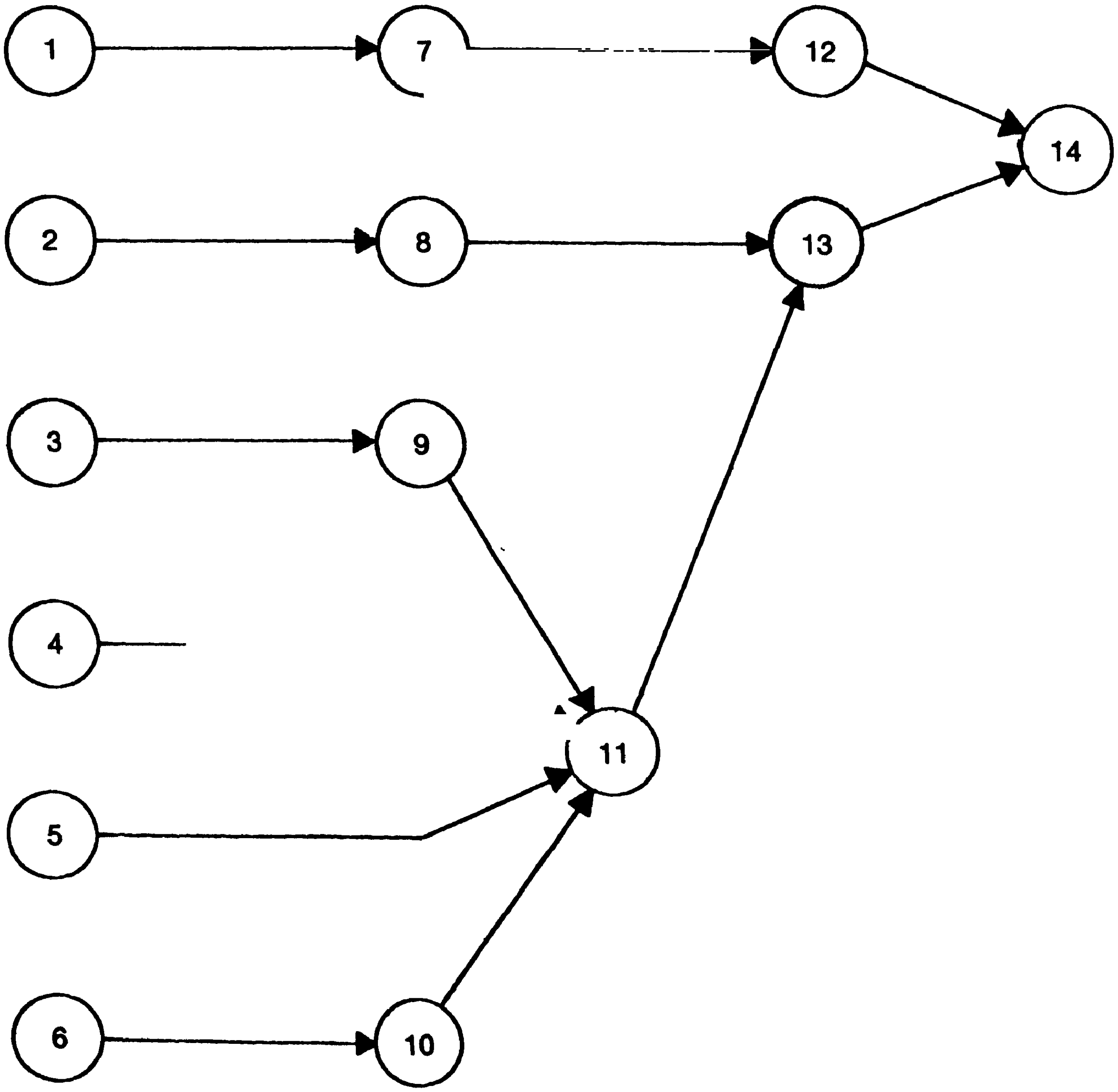


FIGURE 6.1

DOMESTIC LIGHTING LOAD CURVE FOR SOUTH BOMBAY SAMPLE

March—April 1985

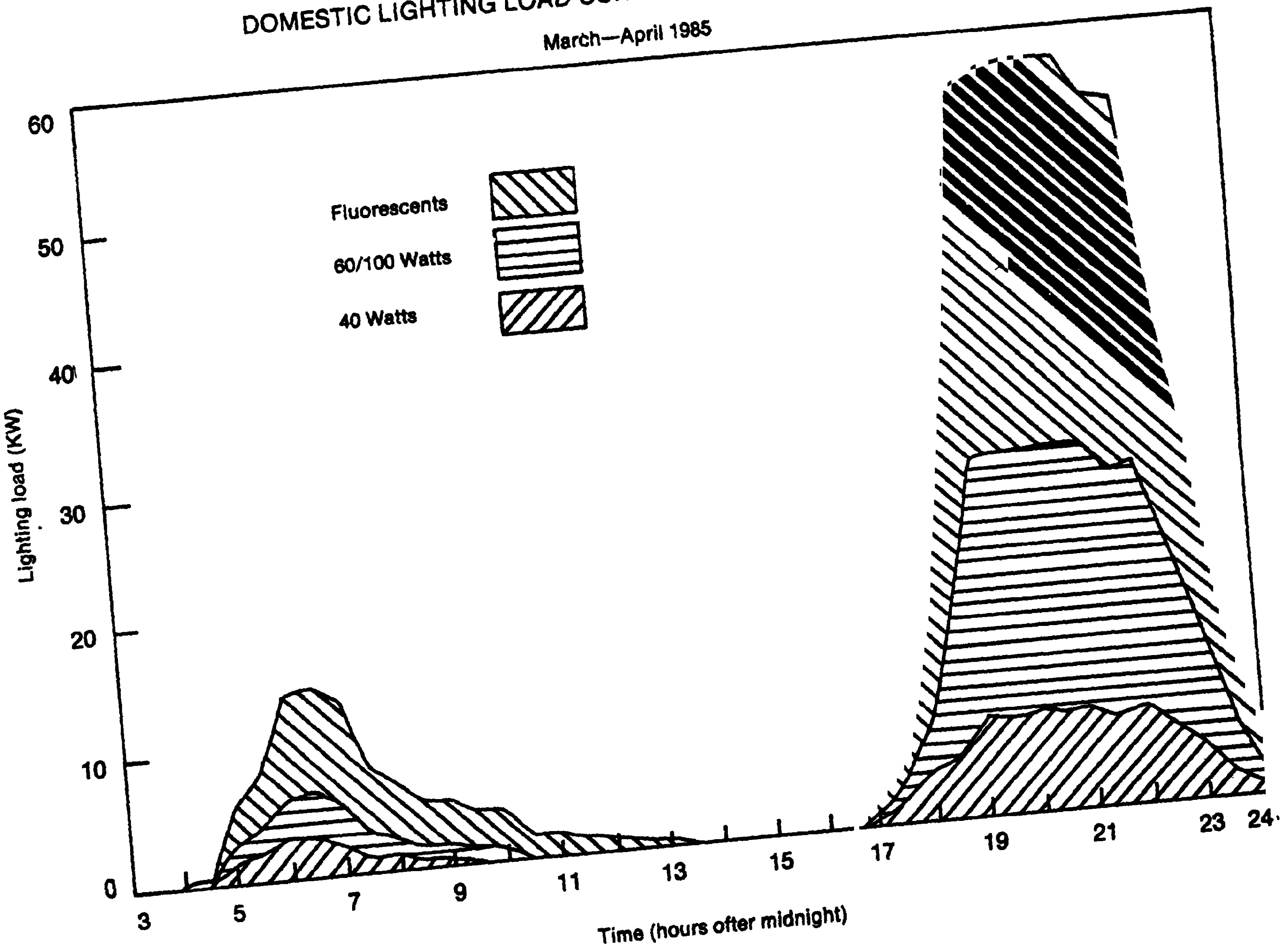


FIGURE 5.2

COMMERCIAL LIGHTING LOAD CURVRE FOR SOUTH BOMBAY SAMPLE

March—April 1985

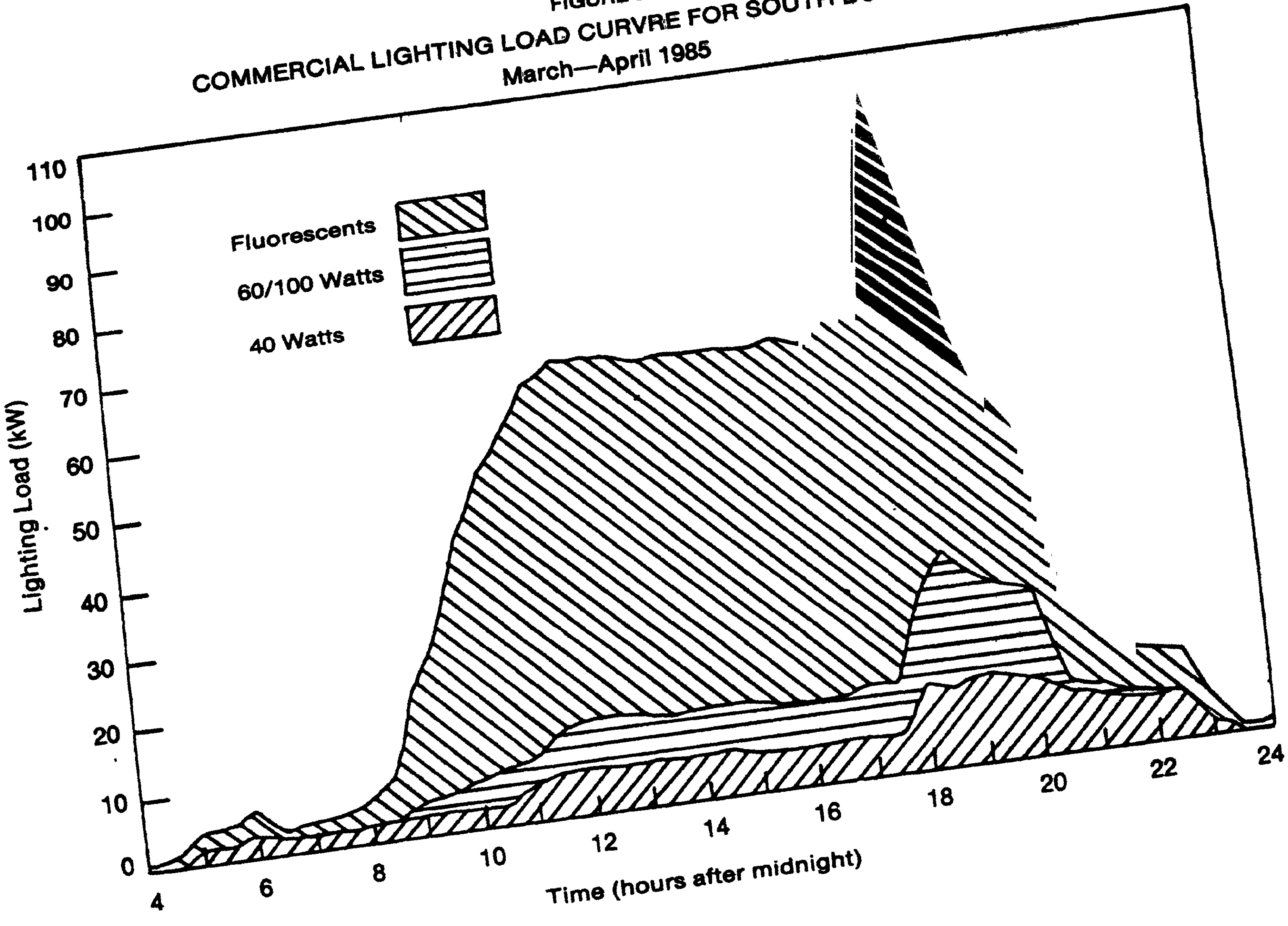


FIGURE 5.3

TOTAL LIGHTING LOAD CURVE FOR SOUTH BOMBAY SAMPLE

(DISAGGREGATED BY CONSUMERS)

March-April 1985

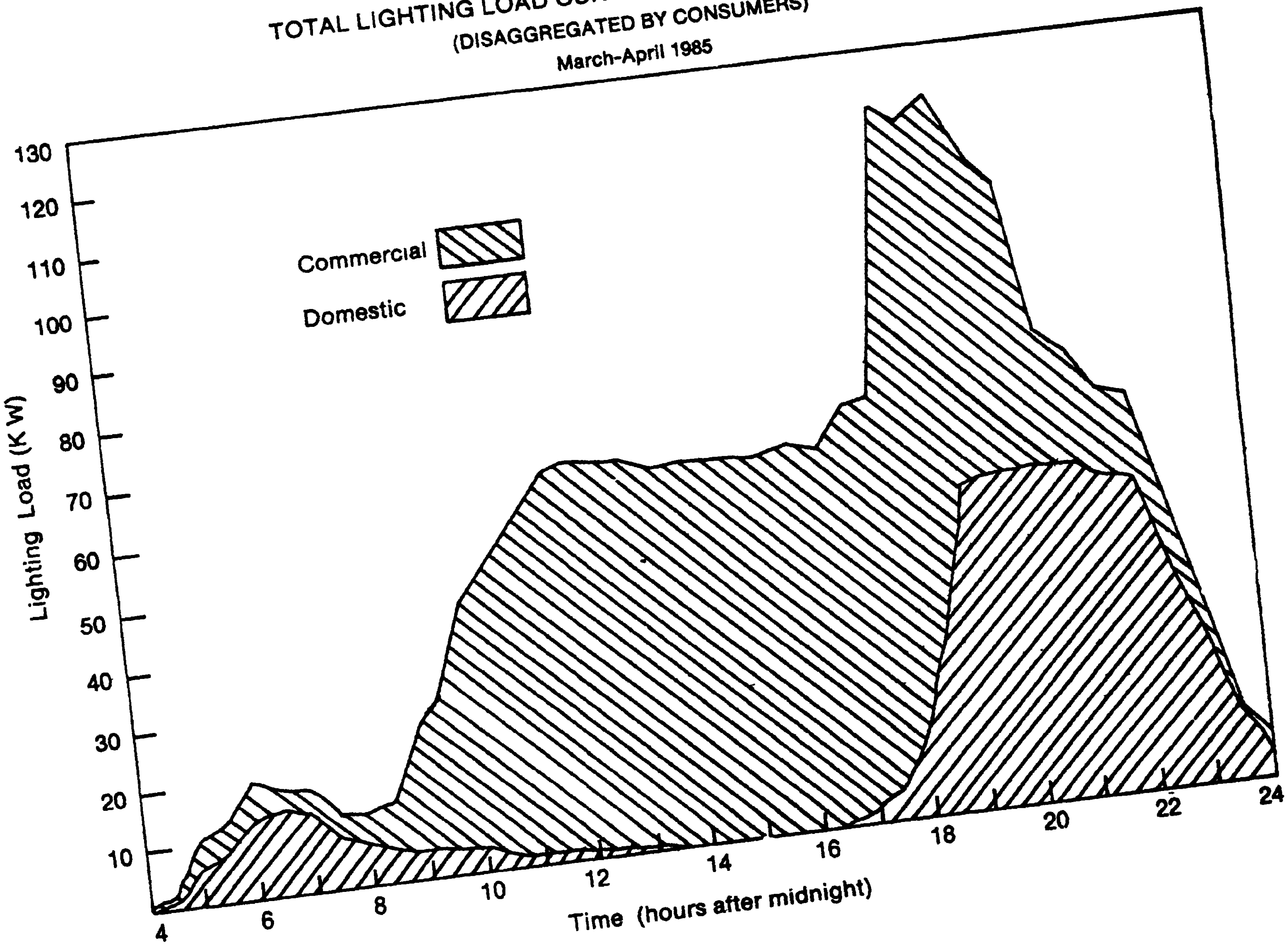


FIGURE 5.4

TOTAL LIGHTING LOAD CURVE FOR SOUTH BOMBAY SAMPLE

(DISAGGREGATED BY LIGHT SOURCES)

March-April 1985

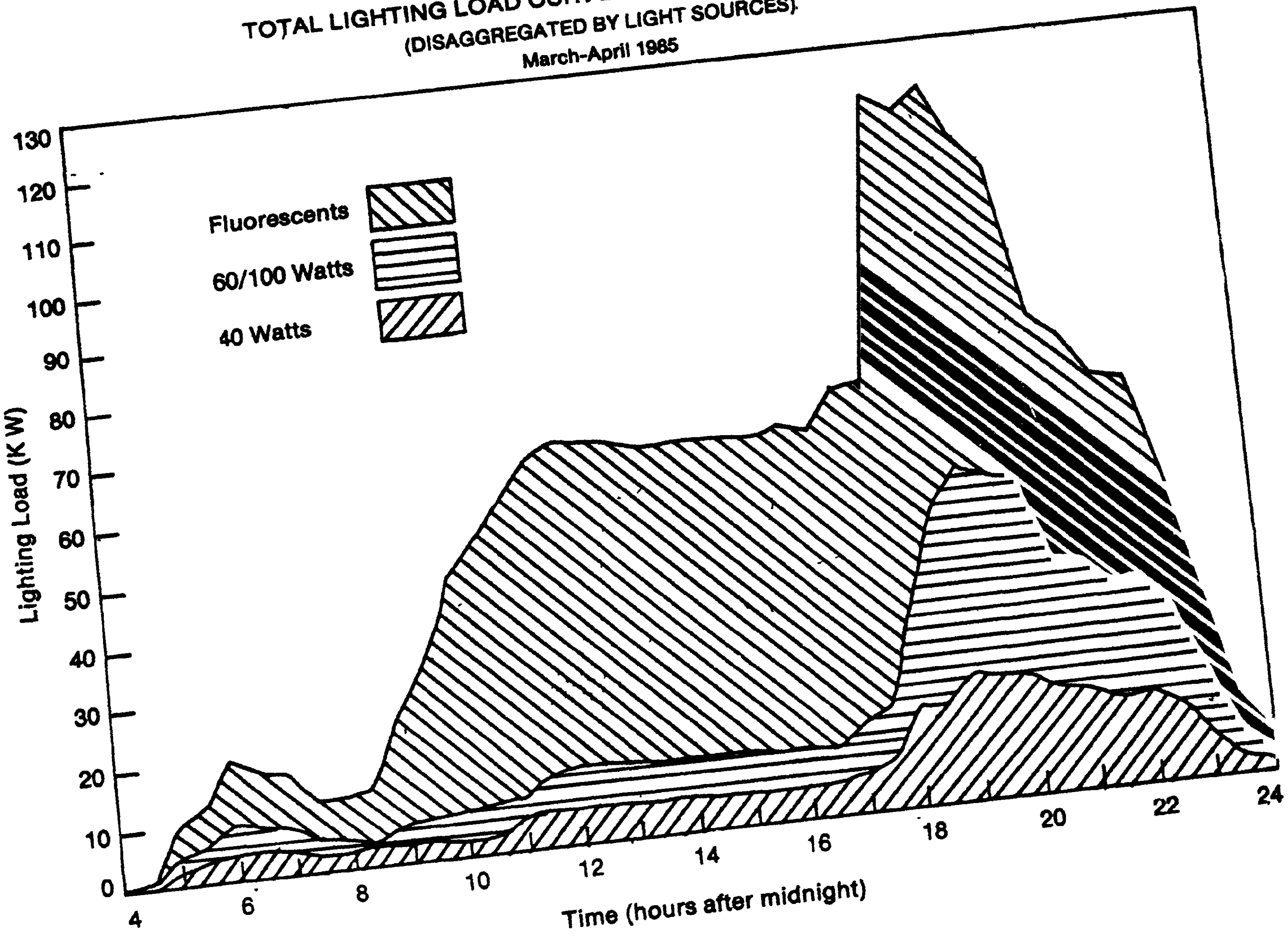


FIGURE 5.5

LIGHT IN SOUTH BOMBAY
DUTY CYCLE OF FLUORESCENT LAMPS
March-April 1985

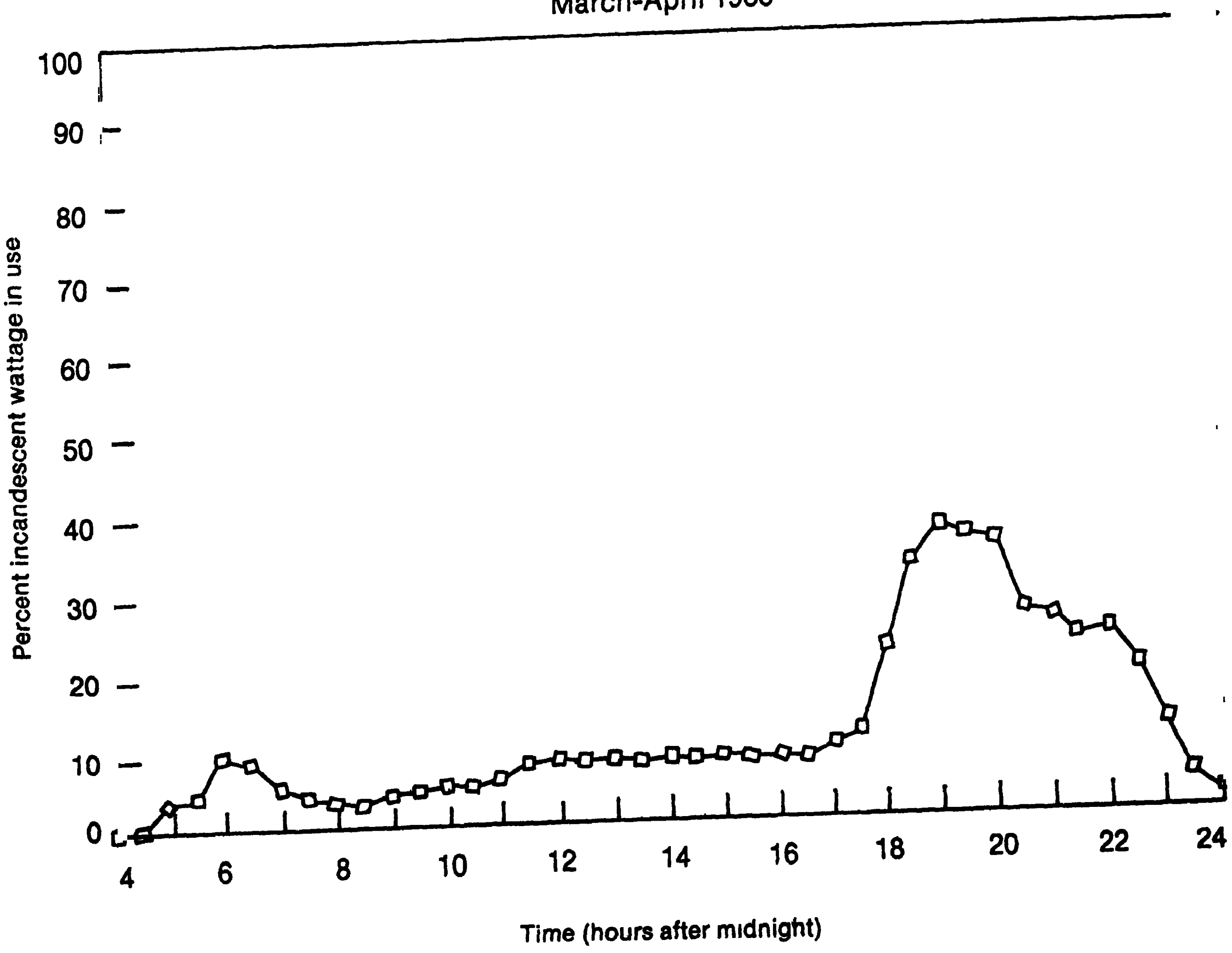


FIGURE 5.6
LIGHTING IN SOUTH BOMBAY
DUTY CYCLE OF INCANDESCENT LAMPS
March-April 1985

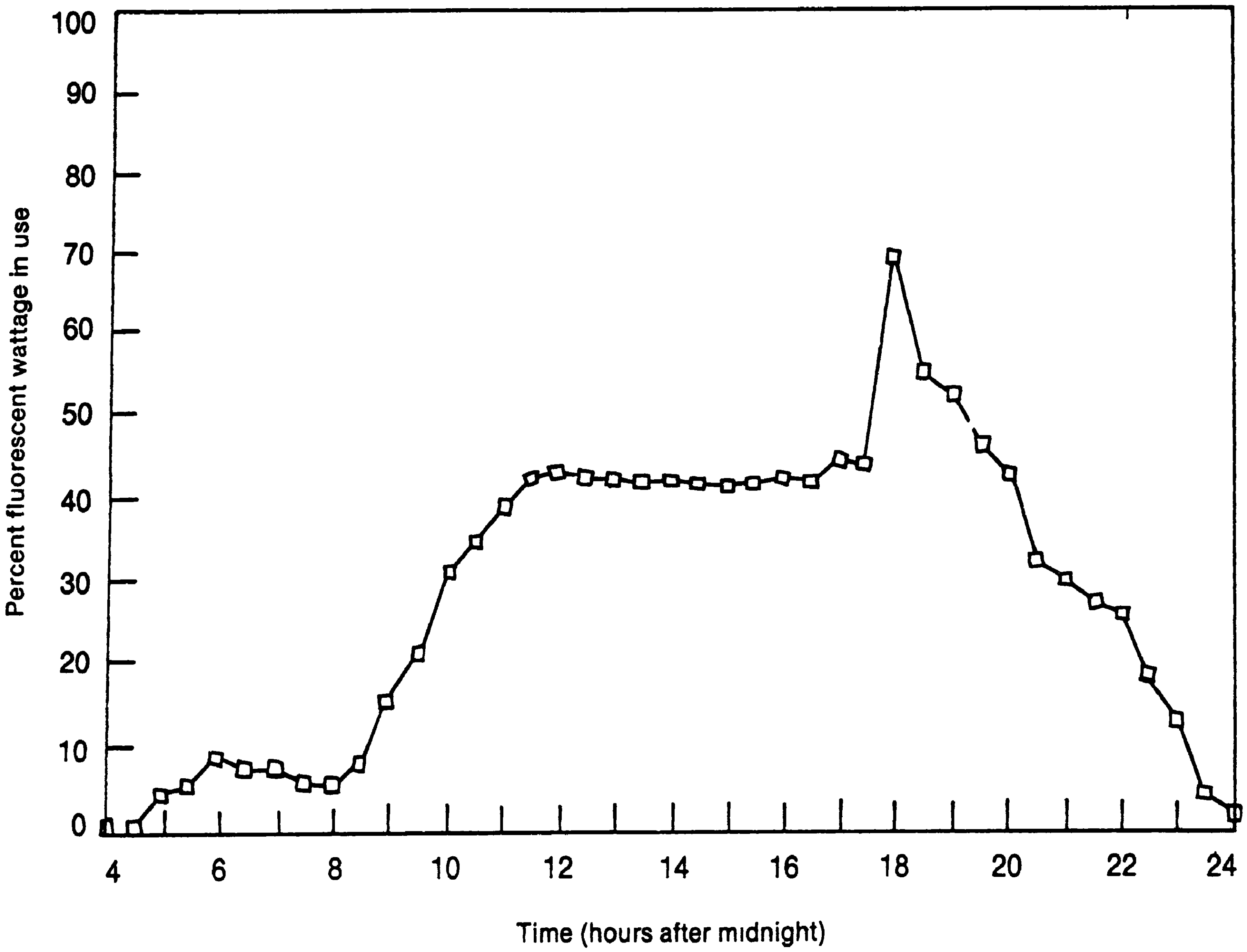
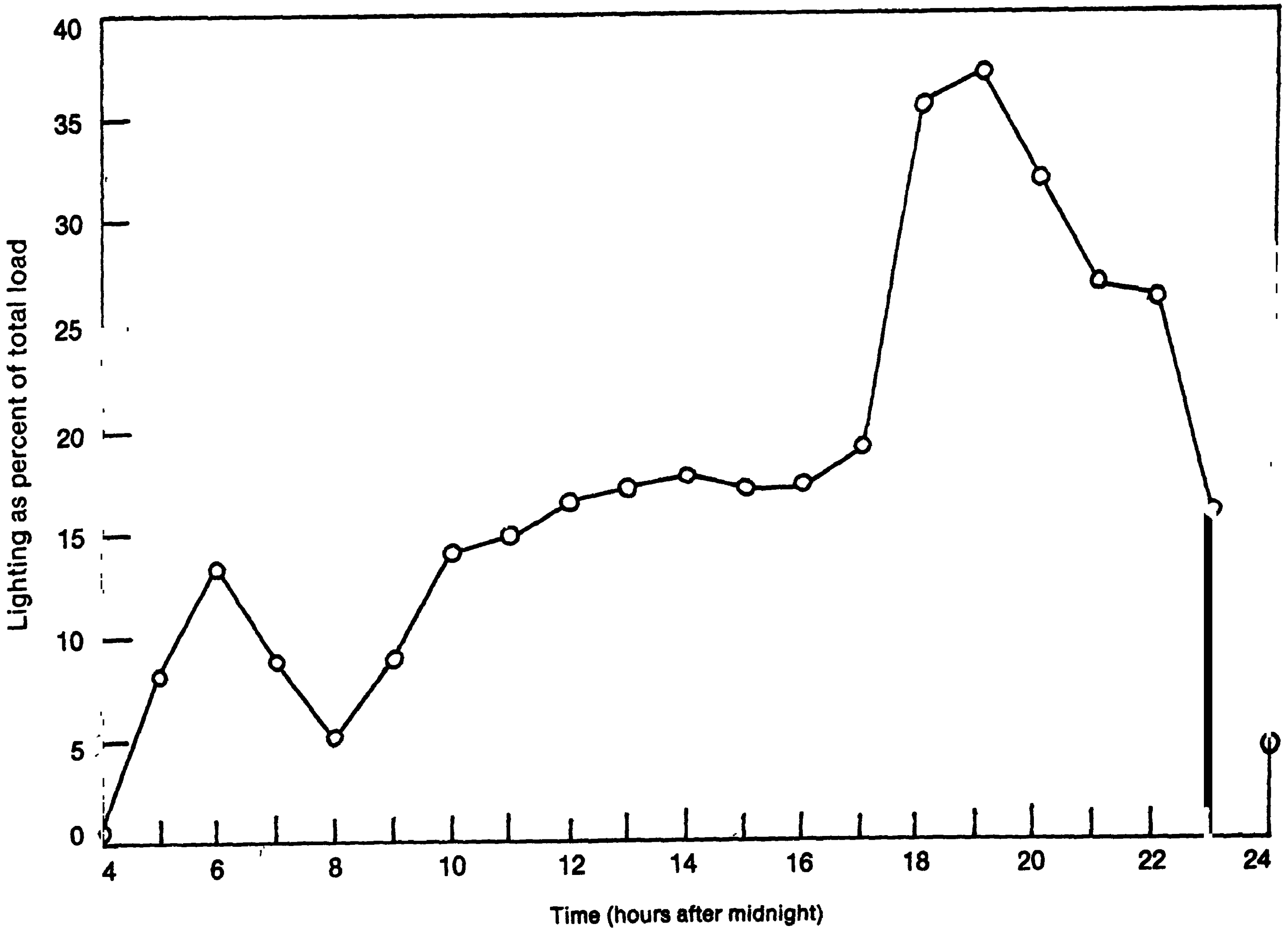


FIGURE 5.7

CONTRIBUTION OF LIGHTING IN SOUTH BOMBAY TO TOTAL LOAD

March—April 1985



APPENDIX—A

METHODOLOGY OF OBTAINING LIGHTING LOAD CONTRIBUTION TO PEAK LOAD BETWEEN 1800-2200 HOURS

INTRODUCTION

This appendix describes a method of processing the data obtained from Tata Railway System for South Bombay, to identify the component of the lighting load that occurs during the peak load hours 1800-2200.

Section 1 deals with the methodology for constructing the unrestricted load demand taking into account decreased load owing to drop in system frequency, and load shedding due to operation of under-frequency relays as well as due to emergency black-outs.

Section 2 describes the methodology of obtaining a piecewise linear and continuous load curve (PLC load curve for short). This load-curve has the advantage that it has no discontinuities unlike in a histogram. It also allows a better estimate of the instantaneous rate of change of load than the histogram does. The PLC load curve is obtained in such a way that the area under the curve continues to equal the total energy demand

Section 3 describes the method of identifying the lighting component of the load by using astronomical data and the PLC load curve. The method proposed in this Section could be subsequently refined by including meteorological data (cloud type and amount) in addition to astronomical data. But this task is left to the future since we would be in a better position to incorporate the refinements once the first attempt to obtain lighting load from the PLC load curve and astronomical data has been made.

Section 4 outlines the next steps, and additional data needs.

Section 1

Suppose that we have entered and manually verified the four hourly data-strings, each of 8760 numbers in length, for the Tata Railway System of Bombay. The four data files are, respectively, the generated power averaged over 60 minutes, hourly average frequency of the system, hourly average amount of emergency load shedding that took place, and the hourly average amount of load shed due to operation of the under-frequency relays.

As described earlier, one then can calculate the actual demand as it would have been in absence of the load-shedding and frequency decreases.

The power demand D is given by:

$D = (G + F + L) \quad (1 + K (1 - H/50))\}$,

Where

G = generated power,
F = Load shed due to under-frequency relays,
L = Load shed by emergency black-outs,
H = system frequency,
K = correction factor (recommended value = 1 5).

Given this data one needs to determine how much of the demand was due to lighting, particularly during the evening peak hours of 1800 Hrs. to 2200 Hrs.

Section 2

Next, one must begin reconstructing a better approximation to the actual load-curve from the data that we have obtained. The data obtained above give the demand averaged over 60 minute periods preceeding the hours against which it is given. This procedure naturally reports the value of the peak-load as equal to the average load during the peak-load hour; and reports the value of the minimum load as the average load during the minimum-load hour. Thus the 60 minute averaging procedure smooths out the actual maxima and minima to a certain extent. This procedure, on the other hand, has the advantage that the area under the load-curve directly gives the total energy generated. For our purposes, however, it is more interesting to look at the rates of change of load, and hence we must obtain from the given data a PLC load curve. The PLC load curve will allow us to estimate better the rate of change of the load, magnitude of the actual peak-load, and at the same time retain the useful property that the total energy generated equals the area under the curve.

Consider a 24 hour period starting from any given hour, say 0200 Hrs. Let the values of the average load for the 24 hours (obtained by the procedure of Section 1) be denoted by a1, a2, a3 . a24. This load curve, if plotted properly, will be in the form of a bar-chart, each bar of height a1, a2, a3... etc, and of width 1 hour, centred on the half-hours preceeding the hours to which the values have been assigned.

The 24 values a1, a2, a3, ... a24 represent the average loads for 60 minutes centred on the half hour preceding each hour. Due to the averaging procedure, already some smoothing of the load-curves has taken place. Load-curve as represented by these 24 numbers is a histogram and hence the rates of change are zero during each hour where the histograms have flat tops, and the value of the load increases discontinuously at the end of 60 minutes and stays constant for the next 60 minutes. From these data we should obtain an approximation which is continuous and piecewise linear at the same time having the desirable property that the area under the load curve equals the total amount of energy supplied during the 24 hour period.

We construct such a PLC load curve by the following procedure Locate 24 points, points h1, h2, h3, ... h24 on the load-curve diagram directly above the consecutive half hour points (i e., 12.30 A.M., 1.30 A.M., 2.30 A.M , etc). If the PLC load curve is obtained by connecting the points h1, h2, h3, ... h24 by straight line segments, one can then derive the following set of equations which inter-relates the array of numbers [a1, a2, a3 ... a24] to the array [h1, h2, h3, ... h24].

$$a_i = \frac{h_i - 1}{4} + \frac{h_i}{2} + \frac{h_i + 1}{4}$$

This equation produces a tri-diagonal matrix relation between the arrays $[a_i]$ and $[h_j]$ which can be inverted to obtain the $[h_i]$'s

There is a little problem which at first appears formidable. Since equation (1) relates three consecutive values of h_i to one value of a_i, we shall need to invert a tridiagonal matrix of dimension 8760 x 8760 to obtain the array $[h_j]$. This indeed would be a formidable requirement but for the fact that the matrix to be inverted is tridiagonal [definition: a tridiagonal matrix is a square matrix with all elements zero except those along the main diagonal and the super—and the sub-diagonal]. Tridiagonal matrices of any size can be inverted fast and accurately by using an algorithm called TDMA which incorporates Gaussian elimination.

There is a further computational advantage to be gained by making the reasonable assumption that the demand does not vary between some three fixed consecutive hours of each 24-hour period, say 2:00 A.M. to 4:00 A.M. In this case the 24 hour cycle can begin at 3:00 A.M. and the value of h1 at 3:00 A.M. does not need to be connected with the value of a24 of the preceding 24 hour cycle (since a24 of the preceding day will then equal a1 of this day) and similarly, the value of h24 at 2.00 A.M. does not need to be connected with a1 at 3:00 A.M. of the next 24 hour cycle. This brings down the size of the tridiagonal matrix to be inverted enormously-to just 24 x 24. One matrix inversion per day for 365 days will thus produce for us 365 sets of 24 values of h_i. When these are consecutively connected, we shall obtain the PLC load curve for the full year.The area under this curve will still equal the total energy demand.

Section 3

The sunrise sunset times for Bombay for the year 1983 are given at the end of this appendix

One can probably assume that all electric lighting to replace daylighting comes on within ± 30 minutes of sunset time. If this transition period (from daylighting to electric lighting) is shorter than 60 minutes then we are unable to resolve it with the available sampling rate for electric load of one observation per hour. If the transition period is longer than 60 minutes, as the case may be for overcast days—and for this the meteorological correction would perhaps be important—we could and should take this into account. The assumption of the transition period (from natural to electric lighting) symmetrically situated ± 30 minutes about the sunset time is presently made for the sake of illustration and we perhaps need to refine it or back it up with some empirical observation.

The change of load over the transition period centred on the time of sunset represents the sum of two effects· the increase in load due to the turning on of electric lights, in addition to the change in non-lighting load which has nothing to do with sunset time. To obtain the change in non-lighting load at that particular clock time we can use the PLC load-curves for all those days of the year when the sunset time is outside the transition period centred on the sunset time of the day under consideration.

Example. Suppose that sunset on January 1, 1984 occurred in Bombay at 6.10 P.M. From the PLC load curve for that date we obtained the increase in load from 5·40 to 6:40. Suppose this is 110 MW. This increase in load has occurred due to change in non-lighting load as well as switching on of electric lights due to sunset. To obtain the change in non-lighting load at 6:10 ± 30 minutes, consider the PLC load curves of all days having sunsets outside the time period 6.10 ± 30 minutes. The average change in the load during this period 6:10 ± 30 minutes for these days can be considered a conservative estimate of the change in non-lighting load during 6:10 ± 30 minutes. Suppose this is 30 MW. Then the lighting contribution must be 110—30 = 80MW.

The reason the above estimate is conservative is that owing to the limited variation in sunset time in Bombay (a maximum variation of one hour and 20 minutes) we are unable to obtain data for non-lighting load changes by considering those days where the sunset time differs from that of the date under consideration by more than one transition period (i.e. in our example it is difficult to find days when the sunset will be outside the period of 6.10 ± one hour). Owing to this limitation, the non-lighting load computed from the above procedure will contain small portions of changes in the lighting load itself. One could try to be clever and balance out these effects by averaging over equal number of sunsets equidistantly placed (of course, outside ± 30 minutes) around the sunset under consideration.

Alternative strategies for identifying the lighting load are possible. One could simply look at the time of occurrence of the peak load, as located by the position of the centre of Full-Width-at-Half-Maximum This quantity is less dependent on the time of sampling and would change smoothly rather than descretely as the peak load shifts from one hour interval to the next. This approach too could be experimented with once the PLC load curve is available.

Section 4

The increase in the load over the transition period centred at sunset time reduced by the change in non-lighting load at that time gives the amount of power consumed by electric lighting that replaces natural lighting. This by itself is not enough to estimate savings obtained by introduction of more efficient lighting technologies We need to estimate the present average luminous efficacy of the electric lighting that gets switched on during the transition period. From this average luminous efficacy one could estimate the decrease in electric demand resulting from improved lighting technologies with higher luminous efficacies. The average luminous efficacy of lighting in South Bombay is not likely to be representative of that for all India The Bombay figure is likely to be higher than the national average Only field surveys can determine the average luminous efficacies for Bombay and all of India

BOMBAY SUNRISE AND SUNSET TIMINGS—1984

JANUARY

Date	Sunrise	Sunset
1	07:13	18:10
2	07:13	18:10
3	07:14	18:11
4	07:14	18:11
5	07:14	18:12
6	07:14	18:12
7	07:15	18:13
8	07:15	18:14
9	07:15	18:14
10	07:15	18:14
11	07:15	18:16
12	07:15	18:16
13	07:16	18:17
14	07:16	18:17
15	07:16	18:17
16	07:16	18:18
17	07:16	18:19
18	07:16	18:20
19	07:16	18:21
20	07:16	18:21
21	07:16	18:22
22	07:16	18:22
23	07:16	18:23
24	07:16	18:24
25	07:16	18:25
26	07:16	18:25
27	07:15	18:27
28	07:15	18:27
29	07:15	18:27
30	07:15	18:28
31	07.14	18.28

Sunrise/Sunset Timings—Bombay

FEBRUARY

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	07:14	18:28	16	07:08	18.37
2	07:14	18:29	17	07:07	18·38
3	07:14	18:30	18	07:07	18.38
4	07:13	18:30	19	07:05	18:39
5	07:13	18:31	20	07:05	18:39
6	07:12	18:31	21	07:05	18·39
7	07:12	18:32	22	07:04	18:40
8	07:12	18:33	23	07:04	18 40
9	07:11	18:34	24	07:03	18:41
10	07:11	18:34	25	07:03	18:41
11	07:10	18:35	26	07:02	18:41
12	07:10	18:35	27	07:01	18:42
13	07:09	18:36	28	07:01	18:42
14	07:09	18.36	29	06:59	18.43
15	07:08	18.37			

Sunrise/Sunset Timings—Bombay

MARCH

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:59	18:44	16	06:48	18:46
2	06:59	18:44	17	06:47	18:47
3	06:59	18:44	18	06:46	18:48
4	06:58	18:44	19	06:45	18:48
5	06:57	18:44	20	06:44	18:48
6	06:57	18:45	21	06:44	18:48
7	06:56	18:45	22	06:43	18:49
8	06:55	18:45	23	06:42	18:49
9	06:54	18:45	24	06:41	18:49
10	06:53	18·45	25	06:40	18:49
11	06:52	18:45	26	06:39	18:50
12	06.51	18:45	27	06:39	18:50
13	06:50	18:46	28	06:38	18:50
14	06:49	18:46	29	06:37	18:50
15	06:48	18:46	30	06:36	18:50
			31	06:35	18:51

Sunrise/Sunset Timings—Bombay

APRIL

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:34	18:51	16	06:22	18:55
2	06:33	18:51	17	06:22	18:55
3	06:33	18:51	18	06:21	18:55
4	06:32	18:52	19	06:20	18:55
5	06:31	18:52	20	06:20	18:56
6	06:30	18:52	21	06:19	18:56
7	06:29	18:52	22	06:18	18:56
8	06:29	18:53	23	06:17	18:57
9	06:28	18:53	24	06:17	18:57
10	06:27	18:53	25	06:16	18:57
11	06:26	18:53	26	06:15	18:57
12	06:25	18:54	27	06:15	18:58
13	06:25	18:54	28	06:14	18:58
14	06:24	18:54	29	06:14	18:58
15	06:23	18:54	30	06:13	18:59

Sunrise/Sunset Timings—Bombay

MAY

Date	Sunrise	Sunset	Date	*Sunrise*	Sunset
1	06:12	18:59	16	06:06	19:04
2	06:12	18:59	17	06:05	19:05
3	06:11	19:00	18	06.05	19:05
4	06.11	19:00	19	06:05	19:05
5	06:10	19:00	20	06:04	19:06
6	06:10	19:01	21	06:04	19:06
7	06 09	19:01	22	06:04	19 07
8	06·09	19:01	23	06:04	19:07
9	06.08	19:02	24	06.03	19·07
10	06 08	19:02	25	06 03	19 08
11	06:07	19.02	26	06·03	19:08
12	06.07	19:03	27	06:03	19:08
13	06·07	19:03	28	06·03	19:09
14	06·06	19:04	29	06.03	19:09
15	06.06	19:04	30	06·03	19:10
			31	06:02	19.10

Sunrise/Sunset Timings—Bombay

JUNE

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:02	19:10	16	06:03	19:15
2	06:02	19:11	17	06:03	19:16
3	06:02	19:11	18	06:03	19:16
4	06:02	19:12	19	06:04	19:16
5	06:02	19:12	20	06:04	19:16
6	06·02	19:12	21	06:04	19:17
7	06 02	19:12	22	06:04	19:17
8	06:02	19:13	23	06:04	19:17
9	06:02	19:13	24	06:05	19:17
10	06:02	19.13	25	06:05	19:17
11	06:02	19:14	26	06:05	19:18
12	06·03	19:14	27	06:05	19:18
13	06:03	19:14	28	06:06	19:18
14	06:03	19:15	29	06:06	19:18
15	06:03	19:15	30	06:06	19:18

Sunrise/Sunset Timings—Bombay

JULY

Date	Sunrise	Sunset
1	06:07	19:18
2	06:07	19:18
3	06:07	19:18
4	06:08	19:18
5	06:08	19:18
6	06:08	19:18
7	06:08	19:18
8	06:09	19:18
9	06:09	19:18
10	06:10	19:18
11	06:10	19:18
12	06:10	19:18
13	06:11	19:18
14	06:11	19:18
15	06:11	19:18
16	06:12	19:18
17	06:12	19:17
18	06:12	19:17
19	06:13	19:17
20	06:13	19:17
21	06:13	19:17
22	06:14	19:16
23	06:14	19:16
24	06:14	19:16
25	06:15	19:15
26	06:15	19:15
27	06:15	19:15
28	06:16	19:14
29	06:16	19:14
30	06:16	19:14
31	06:17	19:13

Sunrise/Sunset Timings—Bombay

AUGUST

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:17	19:13	16	06:21	19:04
2	06:17	19:12	17	06:22	19:04
3	06:18	19:12	18	06:22	19.03
4	06:18	19:11	19	06:22	19:02
5	06:18	19:11	20	06:22	19:02
6	06:19	19:10	21	06:23	19:01
7	06 19	19:10	22	06:23	19:00
8	06:19	19:09	23	06:23	18:59
9	06:19	19:09	24	06:23	18:59
10	06.20	19:08	25	06 24	18:58
11	06:20	19.08	26	06:24	18:57
12	06:20	19:07	27	06:24	18.56
13	06:21	19:06	28	06:24	18.56
14	06:21	19 06	29	06 24	18:55
15	06 21	19.05	30	06:25	18.54
			31	06:25	18:53

Sunrise/Sunset Timings—Bombay

SEPTEMBER

Date	*Sunrise*	Sunset	Date	Sunrise	Sunset
1	06.25	18:52	16	06:28	18:40
2	06.25	18:51	17	06:28	18:39
3	06·25	18:51	18	06:28	18:38
4	06:25	18:50	19	06:28	18:37
5	06.26	18·49	20	06:28	18·36
6	06:26	18.48	21	06:28	18:35
7	06·26	18:47	22	06:29	18:34
8	06·26	18:46	23	06:29	18·33
9	06·26	18.46	24	06:29	18:32
10	06:27	18:45	25	06·29	18:32
11	06:27	18:44	26	06:29	18:31
12	06:27	18:43	27	06:30	18:30
13	06:27	18:42	28	06:30	18:29
14	06:27	18:41	29	06:30	18:28
15	06.27	18:40	30	06:30	18 27

Sunrise/Sunset Timings—Bombay

OCTOBER

Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:30	18:26	16	06:34	18:14
2	06:31	18·26	17	06·35	18:14
3	06:31	18:25	18	06:35	18.13
4	06:31	18:24	19	06:35	18:12
5	06:31	18:23	20	06·36	18:11
6	06:32	18:22	21	06:36	18:11
7	06:32	18.21	22	06:36	18:10
8	06:32	18:21	23	06:37	18:09
9	06:32	18 20	24	06:37	18:09
10	06:33	18:19	25	06:37	18:08
11	06·33	18:18	26	06:38	18:08
12	06:33	18:17	27	06.38	18:07
13	06:33	18:17	28	06·38	18.06
14	06.34	18:16	29	06:39	18·06
15	06:34	18:15	30	06:39	18:05
			31	06:40	18:05

Sunrise/Sunset Timings—Bombay

NOVEMBER

Date	*Sunrise*	Sunset	Date	Sunrise	Sunset
1	06·40	18·04	16	06.48	17:59
2	06:41	18:04	17	06:48	17.59
3	06:41	18:03	18	06:49	17:59
4	06:42	18:03	19	06:50	17:59
5	06.42	18:03	20	06.50	17.58
6	06:42	18·02	21	06:51	17:58
7	06:43	18.02	22	06:51	17.58
8	06:43	18:01	23	06:52	17:58
9	06:44	18:01	24	06.53	17:58
10	06:45	18:01	25	06.53	17:58
11	06:45	18.00	26	06.54	17:58
12	06:46	18:00	27	06:54	17:58
13	06:46	18:00	28	06·55	17.58
14	06:47	18:00	29	06·56	17:58
15	06:47	17:59	30	06·56	17:58

Sunrise/Sunset Timings—Bombay

DECEMBER

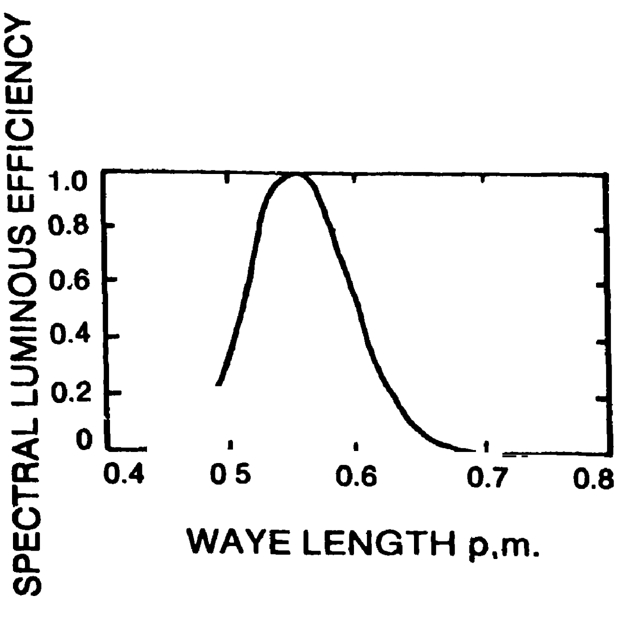
Date	Sunrise	Sunset	Date	Sunrise	Sunset
1	06:57	17:59	16	07:06	18:03
2	06:58	17:59	17	07:07	18:03
3	06:58	17:59	18	07:07	18:03
4	06.59	17:59	19	07:08	18:04
5	06 59	17:59	20	07:08	18:04
6	07:00	17:59	21	07:09	18:05
7	07:01	17:59	22	07:09	18:05
8	07:01	18:00	23	07:10	18:06
9	07 02	18·00	24	07:10	18:06
10	07:02	18:00	25	07:11	18:07
11	07:03	18·01	26	07:11	18:07
12	07:04	18:01	27	07:12	18:08
13	07:04	18:01	28	07.12	18:09
14	07:05	18 02	29	07:12	18:09
15	07·05	18 02	30	07:13	18:10
			31	07.13	18:10

BACKGROUND INFORMATION ON ELECTRIC LIGHTING EFFICIENCY

1. Units of illumination and light source-strength

Light output from a lighting source is measured in SI (International standards) units of LUMEN denoted "ℓm". A LUMEN is a unit of luminous flux : one LUMEN equls the luminous flux emitted within a unit solid angle (1 steradian) by a point source having a uniform istropic intensity of one CANDELA. Alternatively a light source having an intensity of one CANDELA in every direction will be emitting a total luminous flux of 4 π lumens.* A lumen is also equal to the luminous flux received by a unit surface element of a unit sphere centred on a point source having a uniform intesity of one CANDELA. In October '79, the General Conference on Weights and Measures held in Paris redefined the CANDELA as the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hz (corresponding to wavelength=0.555 μm in vacuum) and of which the radiant intensity in that direction is 1/683 watt per steradain.

Human vision operates in two modes. Scotoptic mode in dim light, and photoptic mode in bright light. The relative spectral response of photoptic vision (technically known as "spectral luminous efficiency") is shown below.



Light source strength is measured in CANDELAS Light flux incident on a surface is measured in LUMENS.

The maximum response occurs at a wave length of 0.555μm and has been denoted as 100%. The response for wave length less than 0.4μm and greater than 0.7μm is negligibly small.

The illumination obtained from a light source emitting a line spectrum of several frequencies or emitting a continuous spectrum of frequencies is obtained by intergrating the radiant intensity at each frequency or wave length, with the spectral luminous efficiency (response function of the human eye sketched above), scaled by the overall factor of 683 lumens per watt.

Illumination (in lux) $E = (683 \text{ lumen/ watt}) \int_0^\infty V_\lambda G_\lambda \, d\lambda$

Where V_λ = spectral luminous efficiency at wavelength
G_λ = spectral irradiation of the continuous spectrum at wavelength λ(watt/m^2)

Source strengths in CANDELAS are calculated similarly. For example, consider a source emitting light with frequency $\nu = 540 \times 10^{12}$ Hz ($\lambda = 0.555$ μm) with energy flux of 1/683 watt per steradian in a given direction. The intensity in CANDELAS is given by:

$I = KVJ$

Where K = Constant = 683 LUMENS per watt;

V = Spectral luminous efficiency at the frequency of interest (1.0 for = 0 555 μm)

and J = luminous flux in watts per steradian For the above example,

I=(683 LUMENs per watt) × (1.0) × (1/683 watt per steradian) = 1 CANDELA.

(Recall that 1 CANDELA emits one LUMEN per steradian).

2. Efficiencies of Light Sources

Illumination on a surface is given by the density of luminous flux per unit surface area. The SI unit of illumination is a LUX which is defined as illumination produced by one LUMEN dissipated over 1 square meter. Other units of illumination in use are a PHOT = 1 LUMEN per sq. cm., and foot-candle = 1 lumen per sq. ft.

Luminious efficacy of a light source is a measure of the number of lumens emitted by the light source per watt of energy consumed. Luminous efficacies of several light sources available commercially are shown in the table attached.

Notice that fluorescent and vapour discharge lights need ballasts (also commonly called chokes) which themselves consume some power, and thus the total power required is slightly larger than the nominal power rating of the electric light bulb itself. Even then, the luminous effecacies of electric light sources commercially available for domestic and shop lighting range from a low of 9 lumens/watt for incandescent lamps to a high of 58 lumens/watt for the white fluorescent lights. More information on luminous efficacies, lifetimes, etc., of various electric lights commercially available in India can be obtained from lamp catalogues of various good quality lamp manufacturers.

SOME MORE INFORMATION ON LAMP-LIFE AND POWER-FACTOR CAPACITOR COSTS:

Several sources confirm that sensitivity of lamp of fluorescent tubes to variations in supply voltage is much less than that of incandescent lights. Capacitors for improving power factors of fluorescent lamps are always fitted on large installaions of fluorescent lights (e.g. in industry) even in India. These capacitors increase the cost per fitting by about Rs. 25 (as of 1984). This price is expected to considerably decrease owing to econimies of scale if the practice becomes standard.

S.No.	Lamp	Power Consumption (Watts)	Luminous efficacy (lm/W) Lamp	Luminous efficacy (lm/W) Lamp+ballast	Colour rendering index	Average life (hours)
1.	Tungsten Incandescent	25 to 1000	9 to 13	—	100	1000
2	Tungsten Halogen	1000	22	—	100	2000
3.	Fluorescent					
	i) Cool Daylight	TL 20/40/65	49 to 62	32 to 50	77	5000
		TLD 28/36/58	54 to 69	34 to 54		
	ii) White	TL 20/40	58 to 69	38 to 54	65	5000
		TLD 18/36	64 to 77	41 to 58		
4	Compact Fluorescent	9	67	46	85	5000
5.	Blended Lamp	160/250	18 to 21	—	50	5000
6	High Pressure Mercury Vapour	80 to 1000	44 to 57	38 to 54	45	5000
7	High Pressure Sodium Vapour	150/250/400	90 to 118	79 to 107	25	>12000
8	Low Pressure Sodium Vapour	35	125	91	—	>12000
9.	Metal Halide*	250-2000	68 to 95	63 to 90	70	≃ 7000

* Not Available in India

APPENDIX—C

SAMPLING SCHEME FOR THE STUDY ON ELECTRIC CONSUMPTION IN SOUTHERN BOMBAY

BEST has got four receiving sub-stations (22 KV each) for receiving power from the Tata-Railway system, viz., (1) DHARAVI, (2) PAREL, (3) MAHALAXMI and (4) CARNAC. BEST customers are organized into a total of about 700 Reading Files Each Reading File corresponds to a small, geographically contiguous area of Bombay Each receiving sub-station covers a certain number of Reading Files, say "q" And each Reading File contains about 500 meters Thus, total number of meters covered by a sub-station is about 500q

Sampling Scheme

The sampling scheme to be adopted for the proposed study will be SYSTEMATIC SAMPLING IN TWO DIMENSIONS, and is described below stepwise

STEP 1 Select one sub-station

STEP 2 Construct a matrix with the following specifications
- i) Number of columns = Ordered reading files (ordered geographically)
- ii) Number of rows = Ordered meters (ordered by avg units consumed)

STEP 3 Suppose there are rl rows and cp columns

STEP 4 Select a pair of random numbers (i, j) such that $i \leq 1$ and $j \leq p$

STEP 5 Then the selected rows in the samples are, i, $i+1$, $i+21$, $i+31$, , $i+(r-1)1$, and the selected column are, j, $j+p$, $j+2p$, $j+3p$, , $j+(c-1)p$

STEP 6 Sample size will be rc

STEP 7 Finally, the points at which the "r" selected rows and "c" selected columns intersect determine completely the position of "rc" selected units in the sample

Estimation Procedure

Let N, n and k be the population size, sample size and number of systematic sample respectively, such that $N=nk$ Let also, y_{ij} denote the observation on the unit bearing serial number $i+(j-1)k$ in the population, with $i=1,2,3 .\quad , k$, $j=1,2,3, \quad , n$

Suppose the random number drawn less than or equal to k is i, the sample selected then consists of all the units with the serial numbers listed in the i-th column in the following table

TABLE

Schematic Diagram Showing the Serial Number of the Unit in the Population in Terms of the Cluster Number and its Serial Position in the Cluster.

Row Number		Cluster Number				
	1	2	...	i	...	k
1	1	2	...	i	...	k
2	1+k	2+k	...	i+k	..	2k
3	1+2k	2+2k	...	i+2k	...	3k
.						
.						
.						
.						
j	1+(j−1)k	2+(j−1)k	...	i+(j−1)k	...	jk
.						
.						
.						
.						
n	1+(n−1)k	2+(n−1)k	..	i+(n−1)k	...	nk

(A) The Sample Mean and Population Mean:

SAMPLE MEAN $= \bar{y}_{i.} = (1/n) \sum_{j=1}^{n} y_{ij}$ — (1)

POPULATION MEAN $= \bar{y}_{..} = (1/nk) \sum_{i=1}^{k} \sum_{j=1}^{n} y_{ij}$ — (2)

Sample mean is unbiased estimate of Population mean

(B) The Variance of the Sample mean

VARIANCE OF THE SAMPLE MEAN $=$ VAR $(\bar{y}_{i.})$.

VAR $(\bar{y}_{i.}) = (1/k) \sum_{i=1}^{k} (\bar{y}_{i.} - \bar{y}_{..})^2$ — (3)

(C) Use of INTERPENETRATING SAMPLES for estimation of variance

Variance cannot be unbiassedly estimated from a single systematic sample A way out is to make use of the method of INTERPENETRATING SAMPLES, where two or more independent systematic samples are taken from the population. Method of estimation by this technique is given below:

STEP 1: Suppose we take "a" independent systematic samples from the population, where $a \geqslant 2$.

STEP 2: Get sample means from each of the "a" samples as given by equation (1), (i.e., $\bar{y}_{i.}$ "s"). These sample means are the unbiased estimates of the population mean ($\bar{y}_{..}$).

Hence, unbiased combined estimate of the population mean is given by:

$$\bar{y} = (1/a) \sum_{i=1}^{a} \bar{y}_{i.} \qquad \text{—(4)}$$

Also, estimated variance would be,

$$\text{Est. VAR } (\bar{y}) = (1/a(a-1)) \sum_{i=1}^{a} (\bar{y}_{i.} - \bar{y})^2 \qquad \text{—(5)}$$

SUMMARY TABLE OF ESTIMATION OF MEAN AND VARIANCE

$$\text{Est. Mean} = \bar{y} = (1/a) \sum_{i=1}^{a} \bar{y}_{i}\ ,\ a \geqslant 2$$

$$\text{Est. Variance} = \text{VAR } (\bar{y}) = 1/(a\ (a-1)) \sum_{i=1}^{a} (\bar{y}_{i.} - \bar{y})^2$$

USE OF THIS SAMPLING SCHEME FOR THE PROPOSED STUDY:

(I) Selection of the systematic sample:

STEP 1: Choose any one receiving sub-station.

STEP 2: Let the sub-station have 200 reading files Thus $q = 200$.

STEP 3 Each reading file has about 500 reading meters.

STEP 4: Size of the matrix becomes (500 * 200).

STEP 5 Population size or total number of meters under that sub-station equals 1,00,000 (= N).

STEP 6. Total number of rows, $r1 = 500$. Total number of columns, $cp = 200$.
Where, $r = 5$, $1 = 100$, $c = 5$, $p = 40$

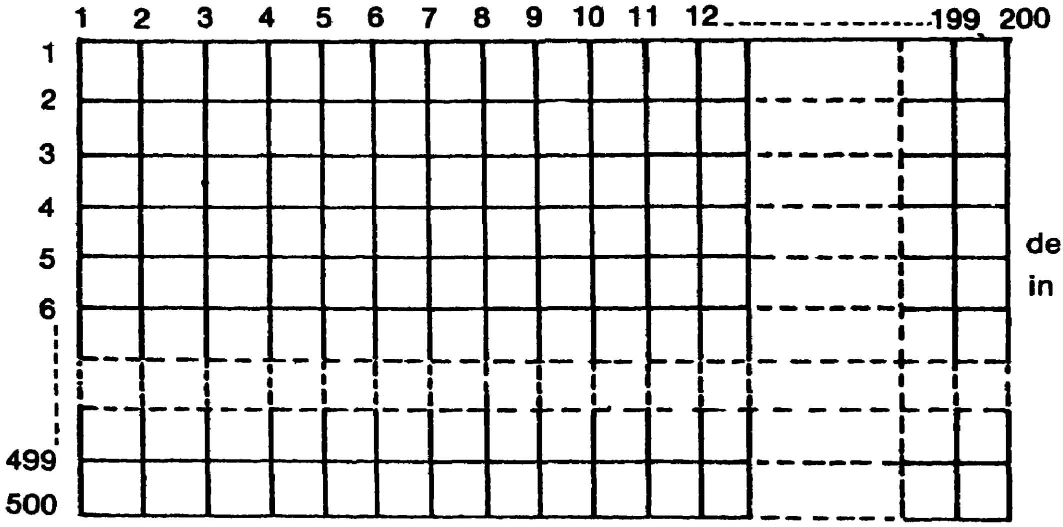
STEP 7· Select a pair of random numbers (i, j), such that $i \leqslant 1$ (= 100), and $j \leqslant p$ (= 40).
Let $i = 2$ and $j = 5$.

STEP 8: Selected rows in the sample will be,
i, i+1, i+21, ...,i+(r−1) 1; i.e., 2, 102, 202, 302, 402.
And, selected columns in the sample will be, j, j+p, j+2p,.........., j+(c−1)p; i.e., 5, 45, 85, ...,325.

STEP 9: Sample size becomes "rc", such that $rc = 25$.

Aligned systematic sample

denote first 'unit selected in the sample.



denote first unit selected in the sample.

(II) Estimation of Sample Mean and Variance:

STEP 1: Suppose we select 8 systematic samples from the selected sub-station. Therefore, a = 8

STEP 2: n = 25

STEP 3: Calculate $\bar{y}_{i.}$ for the 8 selected systematic samples by using the following formula,

$$\bar{y}_{i.} = (1/25) \sum_{j=1}^{25} y_{ij} \quad ; i = 1, 2, \ldots, 8$$

STEP 4. Estimated population mean will be,

$$\bar{y} = (1/8) \sum_{i=1}^{8} \bar{y}_{i.}$$

STEP 5: Estimated variance of the sample mean will be,

$$VAR(\bar{y}) = (1/8*7) \sum_{i=1}^{8} (\bar{y}-\bar{y})^2$$

STEP 6. Thus total number of systematic samples drawn from the selected sub-station is (8*25) = 200

STEP 7: Repeat the same procedure for other three sub-stations also.

STEP 8: Finally, pool the estimates both for mean and variance and obtain the result.

NOTE: Total number of units to be surveyed will be nearly 800

REFERENCES:

1. Sukhatme, P.V & B V. Sukhatme, Sampling Theory of Surveys with applications, Indian Society of Agricultural Statistics.
2. Goon, Gupta & Dasgupta; Fundamentals of statistics; volume—II, World book press, Calcutta.

APPENDIX—D

IMPROVED SAMPLING SCHEME FOR THE SURVEY

This appendix deals with improvement in the sampling strategy suggested by, the Director, Bureau of Economics of Statistics, Govt. of Maharashtra The sampling strategy that we had proposed has already been described in Appendix C of this project report. The following improvements in sampling strategy were adopted.

The reading files in South Bombay will be arranged in a sequence such that every reading file is geographically contiguous with its two immediate neighbours in the sequence. Within each reading file all the meters will be sorted in increasing order of average number of units consumed over the past 12 months.

The total number of meters in the files is about 3 2 lakhs The sample size should be about 800. It turns out that every 394th meter, on the average, should be sampled from the list.

The reading files in South Bombay are divided into ten different 22 KV sub-stations. All these sub-stations are supplied from Carnac receiving station. We should obtain a list of 10 random numbers which are evenly distributed within the interval 1-394 One random number should be assigned in each sub-station This random number should be used as the initial offset in selecting the samples from reading files belonging to that sub-station area This is the first measure to ensure that some insidious periodicity in the sampling selection scheme does not ruin the representativeness of the samples selected.

The second measure to prevent periodic sample selection is as follows·

1. For a given 22 KV sub-station begin the sample selection by skipping first R meters of the first reading file starting from its low-end, where R is the random number assigned to that sub-station

2 Select every 394th meter in the first reading file, keep track of the remainder of the count left at the end of the first reading file

3 Start sample selection from the second reading file by counting the meters from the high-end of the second reading file taking into account the remainder of the meters left over from the first reading file Traverse the file from the high-end to the low-end i e in the direction opposite to that used for the first reading file. Again keep track of the remainder left over at the low-end of the second reading file and carry over at the low-end of the second reading file and carry it over when selecting sample from the third reading file.

4 The third reading file should be scanned from the low-end taking into account the remainder from the previous reading file and selecting every 394th meter traversing in this way towards the high-end of the reading file. This procedure should be followed throughout the area assigned to that sub-station Consecutive reading files should be traversed in opposite sense.

The remainders should be carried over to the next reading file during sample selection. This procedure ensures that even if 394 is close to a sub-multiple of the average number of meters in each reading file, periodic sample selection would not occur. When one goes from one sub-station area to another one, a different random number is used as the initial offset as described earlier. This is the second measure to avoid quasi-periodic sampling.

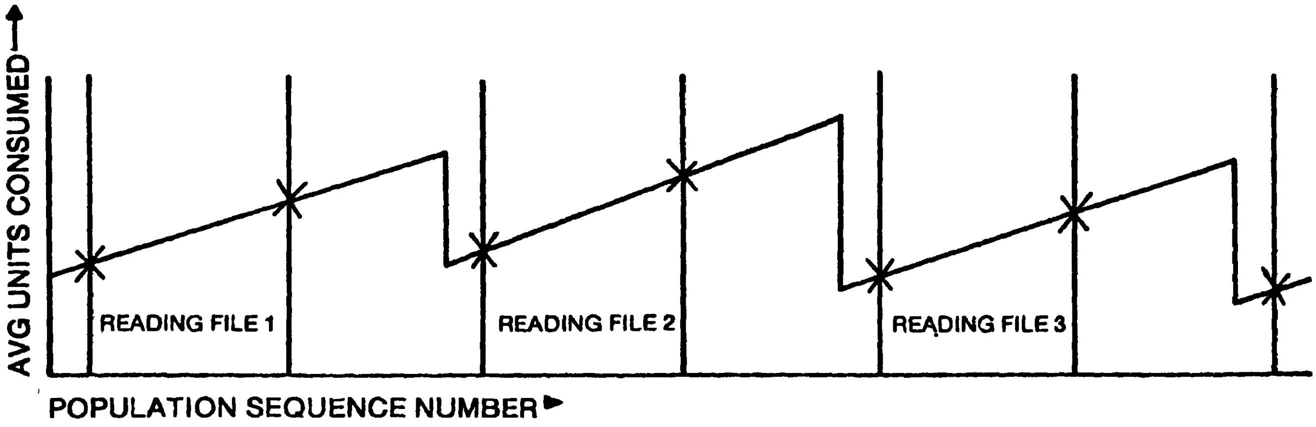
Graphically the danger of periodic sampling is illustrated as in Fig. D1.

However, following the sample strategy described here, the selection will be as shown in Fig D2 below. Notice how with this procedure we avoid the periodic bias in the selected samples.

Immediate neighbours in the sorted list will be chosen as alternates if the meter selected in the original sample cannot be surveyed. This substitution ensures that we do not select a substitute meter at random but from the locality and with average consumption rate similar to the one which could not be interviewed. Four alternate meters to each one in a sample will be provided to investigators. This should ensure almost 100% success rate. If for a particular sample-meter none of the alternates nor the original can be interviewed, it is recommended that we should duplicate data obtained from the same sub-station area with a meter close to the use-category of the failed interview, and substitute it in the place of the failed interview

FIGURE D1

NOTE HOW HIGH CONSUMERS HAVE BEEN EXCLUDED



SAMPLES SELECTED ARE MARKED X

SAMPLING INTERVAL IS A CLOSE SUBMULTIPLE OF AVG FILE LENGTH

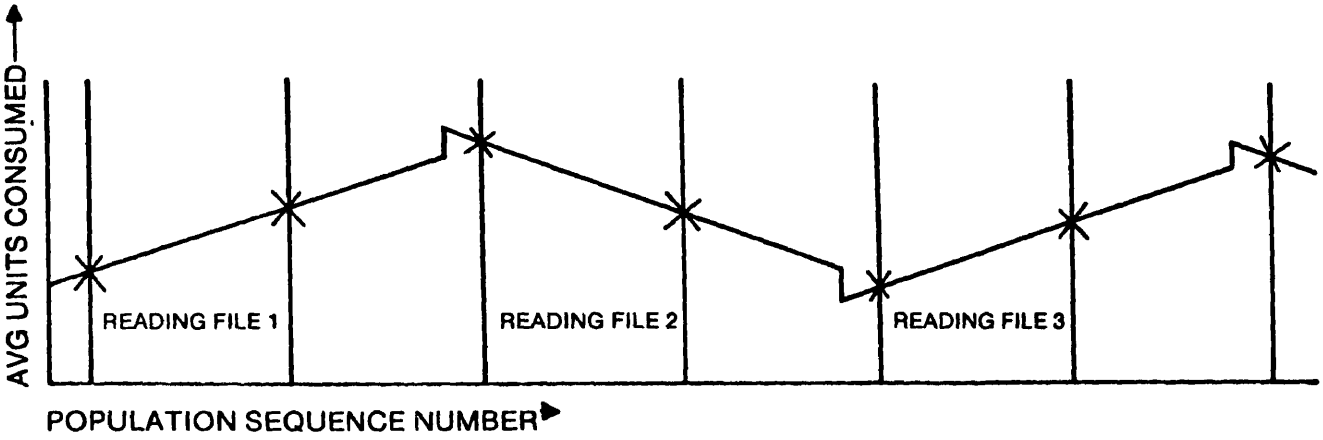


FIGURE D2

NOTE HOW BIAS/IN SAMPLE IS CANCELLED BY COUNTERPOSED FILES

APPENDIX—E

TERI STUDY ON ENERGY EFFICIENT LIGHTING DOMESTIC UNITS

A. Identification

1. Name:
2. Address:
3. No. of family members residing:
4. No. of students at home (of the above):
5. Floor Area:
6. No. of rooms (excluding bathroom/balcony):
7. Name of Respondent:
8. Average monthly income of the family:

(tick the relevant group)

< Rs. 1000
Rs. 1001—Rs. 2500
Rs. 2501—Rs 4000
> Rs. 4000

B. Lighting

		Incandescent	Flourescent
1.	No of lamps in use		
2.	< 40 watts		
	41—99 watts		
	100 watts & above		

3. Details regarding switching on and off of lights:

	Time	Incandescent < 40W	Incandescent > 40W	Flourescent
1. Switch on (morning)				
2. Switch off (morning)				
3. Switch on (night)				
4. Switch off (night)				

5. Any lights on throughout the day
If 'Y', then details Y/N

C. Television

1. TV present at home (Y/N)
(If 'N' then end questionnaire here)

If 'Y' then: B/W set
Colour set

Make:

Screen size:

Normal switch on time:

Normal switch off time:

Any special programs watched:

Programme name	Day of week	Time
1.		
2.		
3.		
4.		

Date: Investigator's Name:

Time Signature:

MRBC's Name:

TERI STUDY ON ENERGY EFFICIENT LIGHTING IN COMMERCIAL/INDUSTRIAL UNITS

A. Identification:

1. Name:
2. Address:
3. Nature of Business.
4. Hours of Business:
5. Weekly Holiday:
6. Floor Area (sq.ft.):
7. If operating in shifts, shift timings.
8. Name of Respondent

B. Lighting:

	Incandescent	Flourescent	Mercury vapour	Sodium vapour
1. No. of lamps in use				
2. < 40 watts				
41-99 watts				
100 watts & above				

3. Any other purpose lamps (specify):

C. Details of day time use (Switch on and off)

	Incandescent		Flourescent		Mercury vapour		Sodium vapour	
	Time	Number	Time	Number	Time	Number	Time	Number
< 40 watts (on)								
(off)								
41-99 watts (on)								
(off)								
100 watts & above (on)								
(off)								

D. Details of night time use (Switch on and off)

	Incandescent		Flourescent		Mercury vapour		Sodium vapour	
	Time	Number	Time	Number	Time	Number	Time	Number
< 40 watts (on)								
(off)								
41–99 watts (on)								
(off)								
100 watts & above (on)								
(off)								

Date:

Time:

Investigator's Name:

Signature:

MRBC's Name: